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REPORT

OF THE

SECRETARY OF THE INTERIOR;

BEING PART OF

THE MESSAGE AND DOCUMENTS

COMMUNICATED TO THE

TWO HOUSES OF CONGRESS

AT THE

BEGINNING OF THE FIRST SESSION OF THE FIFTY-FIRST CONGRESS.

IN FIVE VOLUMES.

VOLUME IV—IN TWO PARTS.

PART 2.

WASHINGTON:
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1890.

TENTH ANNUAL REPORT

OF THE

DIRECTOR

OF THE

UNITED STATES GEOLOGICAL SURVEY

Part II—IRRIGATION

CONTENTS.

UNITED STATES IRRIGATION SURVEY.

ABSTRACT OF FIRST ANNUAL REPORT—1888–1889.

The area of the arid region is about 1,300,000 square miles—one-third of the entire country. I judge that of this area there can be economically reclaimed, by irrigation, within the present generation, at least 150,000 square miles—an empire one-half as large as the entire area now cultivated in the United States. Irrigated, this land would be worth not less than $30 an acre, adding $2,880,000,000 to the wealth of the nation.

In expending the $100,000 appropriated by Congress on October 2, 1888, and a portion of the $250,000 appropriated on March 2, 1889, I have interpreted the law not as authorizing the construction of works of irrigation, but only as directing a comprehensive investigation of prevailing conditions: the whereabouts of irrigable land most eligible for redemption and its segregation for homestead settlement; the amount of available water; the location of reservoir sites and canal sites; the seepage; the evaporation; the vested rights, and how to maintain them; and, generally, the most economical method of bringing the land and the water together.

To this end I have proceeded to expend the money in such a way as to obtain the information required in the shortest time.

The topographic work for making the necessary maps was placed in charge of Prof. A. H. Thompson; the engineering and hydraulic work in charge of Capt. C. E. Dutton. Work was begun in October, 1888, and carried on during 1888 and 1889 in Montana, Idaho, Nevada, California, Utah, New Mexico, and Colorado.

The topographic work consisted of surveys delineating the topographic features of the country; the areas of all drainage basins; the courses of streams; the situation of lakes, springs, and other bodies of water; the positions of possible reservoir sites; the location of dams and canal lines, and the altitude, position, and general character of all irrigable lands.

The hydraulic and engineering work consisted of the measurement of rain-fall and the study of general meteorology; measurement of river flow, evaporation, and matter carried in suspension by water; the ascertainment of the duty of water, and the determination of the

mode and cost of construction of dams and canals, and of the areas and contents of reservoirs.

Following is a tabular summary of work done during the fiscal year:

Table of work during the fiscal year.

States.	Area mapped.			Area surveyed.		
	1888.	1889.	Total.	Scale field work.	Contour interval.	Square miles surveyed.
	Sq. miles.	*Sq. miles.*	*Sq. miles.*		*Feet.*	
California	1,580	3,268	4,848	1 inch to 1 mile	100	1,466
Colorado	13,000	10,200	23,200	do	50 20	12,650
Idaho		1,900	1,900			
Montana	3,600	1,670	5,270	1 inch to 2 miles.	200	3,600
New Mexico	3,800	2,570	6,370	1 inch to 1 mile	100 50	3,800
Nevada	250	1,642	1,892	do	100	250
Total	22,230	21,250	43,480			21,766

Expenditures from October 3, 1888, to June 30, 1889 ..... $172,171.83
Cost per square mile 3.95

Reservoir sites and canal sites located.

	Reservoir sites.			Canal sites.
	Selected for segregation.		Surveyed.	Surveyed.
	Number.	Area in sq. miles.		
Montana	61	1,762	10	3
California	16	252+	12	
Colorado	25	185¼	10	1
Utah	10	75+		
New Mexico	15	399+	1	
Nevada			1	
Total	127	2,673¼	34	4

Total segregations of irrigable lands.

	Acres.
Snake River Basin	11,057,360
Bear River	2,085,320
Upper Missouri and Yellowstone	11,133,440
Owens River Valley	519,000
Rio Grande Valley	5,760,000
Total	30,555,120

The maps referred to in this report are borne in Part I—the Annual Report of the U. S. Geological Survey.

J. W. POWELL,
Director.

IRRIGATION SURVEY—FIRST ANNUAL REPORT.

By J. W. Powell, Director.

ORIGIN OF THE IRRIGATION SURVEY.

In making this the first report of the operations of the Irrigation Survey it seems proper to give a brief history of its origin by Congressional enactment.

In response to Senate resolution of February 13, 1888, relating to the segregation of lands of the public domain capable of irrigation in sections of the United States where irrigation is required, and to places to be reserved for reservoirs and rights of way for ditches and canals, the following letters were transmitted:

Department of the Interior,
Washington, March 31, 1888.

Sir: I have the honor to acknowledge receipt of a resolution of the Senate passed on the 13th of February, 1888, of which the following is a copy:

Resolved, That the Secretary of the Interior be requested to inform the Senate if, in his opinion, it is desirable to authorize the organization in his Department known as the Geological Survey to segregate lands of the public domain capable of irrigation in the sections of the United States where irrigation is required from other lands, and to lay out suitable places to be reserved for reservoirs, and rights of way for ditches and canals, for the purposes of irrigation.

And in response thereto to transmit a copy of a communication from the Commissioner of the General Land Office, under date of February 20, to whom the matter was referred, and a copy of a communication from the Director of the Geological Survey, under date of March 13, to whom the matter was also referred, expressing the views of those officers upon the subject.

And, further, to say that it has been hitherto impossible for me to secure a sufficient opportunity for examination and study to authorize me to comply with the direction of the resolution for an expression of opinion beyond what is here submitted, although, in obedience to

that direction, I have sought to qualify myself in some measure, however imperfectly, to comply with it. It appears from the communication of the Director, as, indeed, must readily occur to intelligent reflection, that the subject involves vast areas of territory, manifold public and private interests, and far-reaching considerations touching results and costs; and also that each separate instance of contemplated action involves peculiar and special inquiries and determinations, so that, although the general desirability of so comprehensive and effective a system of irrigation as Government alone can institute and carry to completion may be readily affirmed, a particular designation of what lands may be segregated and what means may be employed to accomplish any result must be the fruit of distinct and particular inquiry in each case.

It is believed to be possible, by an undertaking on a scale of adequate grandeur, to seize the waters of the Missouri and its tributaries at a proper distance from their sources, and not only to apply them to the reclamation of arid lands in the upper region, but thereby also to benefit the agricultural territories adjacent to its lower currents, and even to mitigate the severity of the effects of the floods of the Mississippi upon the agricultural lands of its borders. Or some lesser river may be restrained of its natural flow and its waters applied only to the advantage of the desert wastes lying in the particular valley through which it runs. Since the adoption of the foregoing resolution, and probably from a contemplation of these considerations, a joint resolution has been passed and approved, directing this Department, "by means of the Director of the Geological Survey"—

to make an examination of that portion of the arid regions of the United States where agriculture is carried on by means of irrigation, as to the natural advantages for the storage of water for irrigating purposes, with the practicability of constructing reservoirs, together with the capacity of the streams and the cost of construction and capacity of reservoirs, and such other facts as bear on the question of storage of water for irrigating purposes.

And another resolution has been adopted by the Senate directing this Department to report what appropriation may be necessary to enable the examination so directed to be made, and also—

to classify the public lands and furnish a map or maps showing the various divisions of the public domain suitable for agricultural, mineral and other purposes, and particularly to segregate the lands susceptible of irrigation, where irrigation is required, from other lands, and designating places for reservoirs, canals and other hydraulic works.

In accordance with the latter resolution a careful estimation of the appropriation which may be deemed necessary is in progress, and will be submitted at the earliest practicable date to the Senate in obedience thereto.

When the products of this inquiry shall be at command, it may be anticipated that there will be disclosed a proper opportunity for an

experimental attempt to establish in some region of the country such a system of storage of water supply and of canals and other conduits for irrigation as shall afford a practical solution of the merits and advantages of governmental interposition of this nature. Without such particular information it seems to be obvious that nothing can be advantageously ventured in the way of opinion, at least in any useful detail; and I respectfully request the acceptance of the accompanying communications as a discharge of the obligation of the resolution of the Senate.

I have the honor to be, very respectfully, your obedient servant,

WM. F. VILAS,
Secretary.

Hon. JOHN J. INGALLS,
President pro tempore of the Senate.

DEPARTMENT OF THE INTERIOR,
GENERAL LAND OFFICE,
Washington, D. C., February 20, 1888.

SIR: I am in receipt of Senate resolution of February 13, 1888, requesting the honorable Secretary of the Interior to inform the Senate if, in his opinion, it is desirable to authorize the organization in his Department known as the Geological Survey to segregate lands of the public domain capable of irrigation in the sections of the United States where irrigation is required, from other lands, and to lay out suitable places to be reserved for reservoirs and rights of way for ditches and canals, for the purposes of irrigation. Said resolution was, on February 14, 1888, referred to this office, for report in duplicate and return of papers, by Hon. D. L. Hawkins, Assistant Secretary.

At present I am not fully informed as to the extent and exact locations of all lands the survey and segregation of which is contemplated by the resolution, nor have I definite means of ascertaining the expense attendant on such work, nor do I suppose that accurate information could be obtained as to these matters in time for the action of Congress at the present session. Whilst it may be desirable that legislation of the character contemplated by the resolution should be had in the future, at the present I am unable to see any urgent necessity for it.

Very respectfully,

S. M. STOCKSLAGER,
Acting Commissioner.

Hon. WM. F. VILAS,
Secretary of the Interior.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., March 13, 1888.

SIR: I have the honor to acknowledge the receipt, by reference of the Hon. D. L. Hawkins, Assistant Secretary, of the following resolution:

IN THE SENATE OF THE UNITED STATES,
February 13, 1888.

Resolved, That the Secretary of the Interior be requested to inform the Senate if, in his opinion, it is desirable to authorize the organization in his Department known as the Geological Survey to segregate lands of the public domain capable of irrigation in the sections of the United States where irrigation is required, from other lands, and to lay out suitable places to be reserved for reservoirs, and rights of way for ditches and canals, for the purposes of irrigation.

Attest:

ANSON G. MCCOOK,
Secretary.

The above resolution was indorsed as follows:

Respectfully referred to Director of Geological Survey for early report, in duplicate, with such information as is in possession of his Bureau, and return of the papers.

In compliance with these instructions, I have the honor to submit the following statement:

Ten years ago a "Report on the Lands of the Arid Region" was submitted to the Commissioner of Public Lands by myself, which report was illustrated by specific data in regard to the lands of Utah. The conclusions therein set forth have not been materially modified by the developments of the last ten years, although during this time agriculture has been greatly extended in the arid region, and the industrial problems involved have been seriously attacked by the State governments of Colorado and California.

The region in which agriculture depends on irrigation includes about four-tenths of the entire area of the United States, not including Alaska. Much of this region is mountainous, and there are extensive districts through which streams flow only in deep gorges, whence they can not be raised for purposes of agriculture. In the more level districts the supply of water is so limited that only a small percentage of the land can be irrigated; and it is in general true that there is a wide range for choice as to the particular tract or tracts of land to which the waters of the several streams may be delivered.

At the present time the greater number of the small streams are utilized for irrigation, so far as is possible, without the storage of water; that is to say, the ordinary flow of water of the smaller streams during the season of growing crops is diverted by canals from the natural channels and served to the land.

The future development of irrigation chiefly depends:

First. On the utilization of the larger streams. These have here-

tofore been largely unused from the fact that great capital or extensive cooperative industry is required.

Second. On the construction of storage basins. In most portions of the United States the season of growing crops is short compared with the entire year, and the greater part of the irrigation works heretofore constructed utilize the water only through the growing season, and the extra-seasonal water is allowed to run to waste.

Third. On the construction of storm-water reservoirs. Throughout the irrigable area of the arid region there are great numbers of small catchment basins through which no perennial waters flow, but within which the storm-waters may be gathered and stored in reservoirs, to be utilized in the season of growing crops.

Fourth. On controlling the entire flow of the smaller streams through the irrigating season. A portion of these waters now runs to waste.

The increase of irrigation by the fourth method depends upon a better selection of sites for headworks, and on better methods of construction, and on better canal systems, and the subject needs no further mention here.

In the third method of increasing the area of irrigation, by the use of storm-water reservoirs, it must be noticed that every catchment area must necessarily be small and the reservoir comparatively small. The area drained must be correspondingly small. These enterprises, therefore, are severally of no great magnitude; they require the ownership or joint control of but small areas of land. The works to be constructed are comparatively inexpensive, and they may therefore be relegated to individual enterprise, cooperative enterprise, or corporate enterprise.

The utilization of the extra-seasonal water of perennial streams can be effected only by the aid of storage reservoirs, and it will be found economic to construct such in great numbers throughout the region, and the acreage of farming land will be vastly increased thereby. There are a few favored valleys lying at the foot of very high mountains which receive water from the melting snows on the mountains at a season when it can be utilized for agriculture, but in most localities the snows melt too early, and their unstored water flows by as waste. In such cases the waste water is many times greater than the water flowing during the farming season, and its storage will correspondingly increase the amount available for agriculture.

A great development of irrigation will come from the use of the large streams, and for this cooperative labor or capital is necessary. Such streams can be economically controlled only for the irrigation of large bodies of land, and their handling has been retarded by the fact that the statutes do not provide for large holdings.

It is recognized as important that the title to water shall vest in that land to which under the most economical distribution for agri-

cultural purposes it belongs. It is necessary that the holders of the land shall combine for the construction of headworks and canals. But the individual can not afford to secure title to a small holding without the assurance of ability to irrigate it, and he can not irrigate but by combining with others. Hence it is that the utilization of the large streams by owners of small tracts must wait until large numbers of the holders of small tracts can be induced to settle simultaneously upon the lands to be irrigated, and be further induced to engage in the corporate or cooperative enterprise necessary to construct great headworks and canals. In view of these difficulties, special provisions appear to be necessary.

The determination of the particular tracts of land to be irrigated, either from great reservoirs or by the utilization of great streams, is controlled by several important considerations. Within the range of country to which it is physically possible to convey the water of a stream, some tracts are more favored in respect to climate, others in respect to soil, others in respect to economy in the construction and maintenance of headworks and canals, others in the conservation of water from evaporation and from seepage in canals, and others in respect to facilities of transportation.

It is also necessary, in order to preserve the proper amount of land for irrigation, to determine in each case the maximum amount of water which can be economically served by the aid of storage reservoirs and the utilization of great streams, and the minimum allowance which, with the particular climate and soil, will serve a unit of land. The selection of tracts, therefore, demands wise discrimination, and can not be advantageously accomplished under the system of contract surveys.

It is undoubtedly true that the greater the delay in the selection of areas for irrigation and of sites for irrigation headworks the greater will be the knowledge which can be brought to bear in making wise selections; but it is also true that the greater the delay the more complex becomes the practical problem by reason of the interference of vested rights. The difficulties arising from vested rights far outweigh, in my judgment, all considerations in favor of delay, and there is even ground for regret that such surveys and selections as are now proposed were not instituted at an earlier stage in the development of the arid region.

The obstructing vested rights may be considered as agricultural and non-agricultural. Obstructing agricultural rights arise in connection with irrigation by the water of small streams. It frequently occurs that a comprehensive system of irrigation in the basin of a river—a system adjusted to the utilization of the water to its greatest extent—will spread the water of the main stream over lower land and the water of smaller tributaries over higher land; but as in the unsystematic development of irrigation the small streams are first

utilized, their water is often applied to the lower land, and the water rights and land rights thus established obstruct the institution of the best general system.

Obstructing non-agricultural vested rights are largely those of pasturage, mining and transportation; and these obstruct chiefly the sites for reservoirs and other headworks, including trunk canals. The range of choice for the selection of irrigation areas is usually so great that such preoccupation as arises in connection with mining and transportation industries does not occasion serious interference. Preoccupation of arable land for purposes of pasturage does not obstruct the development of irrigation, because the bringing of land under irrigation canals so greatly enhances its value that pasturage yields at once to agriculture. Obstruction through the industry of pasturage arises chiefly from the location of stock ranges on sites suitable for storage reservoirs.

The development of the agriculture of the arid region is of national importance in itself. From the fact that the area in which irrigation is necessary is so great, the total area to be irrigated will be great; again, the gold and silver product of the region will increase when mining ceases to be handicapped by expensive subsistence.

The development of irrigation along the base of the Rocky Mountains is of double importance because of its influence on the agriculture of the Lower Mississippi. To store up the water of the Missouri and its main affluents for the purpose of irrigation is to diminish the volume of that flood of the Lower Mississippi which is most destructive by reason of its occurring in the heart of the farming season. Moreover, the great difficulty of the problem of the Lower Mississippi arises from the fact that the river normally makes a deposit there, thus clogging its course and giving to its channel an unstable position. The principal source of the sediment is the Missouri River, and it is carried forward chiefly during flood. With abolition of great Missouri floods the sedimentary load of the Lower Mississippi would be diminished, and the scouring power of the less-loaded floods from the Ohio and the Upper Mississippi would establish for the Lower Mississippi a lower grade and a deeper channel. For every acre reclaimed to agriculture in Montana another acre will be reclaimed in Louisiana; and, in general, all lands redeemed by irrigation on the Great Plains will be equaled by the lands redeemed from floods in the great valley of the Lower Mississippi.

The topographic work of the Geological Survey in the arid regions has from the first been executed with a view to the problems of irrigation, and if such authority as is contemplated by the resolution shall be given to the Survey, the maps now completed and in preparation will serve as a basis for the special work required in respect to irrigation. It will be necessary in addition to make local surveys for the selection of sites for reservoirs, canals, etc., and of irrigation

areas. It will be necessary also to gauge a certain number of representative streams at all seasons of the year, so as to ascertain their total discharge and its seasonal distribution, and also to gauge a greater number of streams at certain seasons determined to be critical.

The district for which the fundamental topographic work has already been accomplished amounts to 120,000 square miles, about 10 per cent. of the entire arid region. The geographic surveys by earlier organizations, covering 405,000 square miles, were made with less detail and less reference to the problems of irrigation, but they will serve the purpose of a reconnaissance.

In extending the geographic work of the Geological Survey over the portion of the arid region not yet covered by it, it will be economical to give to the topographic work a special adjustment in the interest of irrigation.

The Senate resolution and other papers are returned herewith.

I am, with great respect, your obedient servant,

J. W. POWELL,
Director.

The SECRETARY OF THE INTERIOR.

In response to Senate resolution of March 27, 1888, relative to reservoirs for the storage of water in the arid region of the United States, the following letters were transmitted:

DEPARTMENT OF THE INTERIOR,
Washington, May 11, 1888.

SIR: I have the honor to acknowledge the receipt of a resolution of the Senate dated March 27, 1888, as follows:

Resolved, That the Secretary of the Interior is hereby directed to report to the Senate what appropriation is necessary to enable the United States Geological Survey to carry into effect the joint resolution "Directing the Secretary of the Interior, by means of the Geological Survey, to investigate the practicability of constructing reservoirs for the storage of water in the arid region of the United States, and to report to Congress," approved March 20, 1888, and the several acts of Congress requiring such Geological Survey, under the direction of the Secretary of the Interior, to classify the public lands and furnish a map or maps showing the various divisions of the public domain suitable for agricultural, mineral and other purposes; and particularly to segregate the lands susceptible of irrigation, where irrigation is required, from other lands, and designating places for reservoirs, canals, and other hydraulic works.

In response thereto I transmit herewith a report from the Director of the U. S. Geological Survey embodying his views as to the method of conducting the required investigation, and recommending that an appropriation of $250,000 be made for the purpose. I have no

means to make any estimate other than the considerations presented by the Director. The examinations and study made by him have necessarily caused a delay in making response to the resolution, which has been due to no other reason.

Very respectfully,

WM. F. VILAS,
Secretary.

The PRESIDENT PRO TEMPORE OF THE SENATE.

DEPARTMENT OF THE INTERIOR,
U. S. GEOLOGICAL SURVEY,
Washington, D. C., May 3, 1888.

SIR: On the 27th of March, 1888, the following resolution of the United States Senate was transmitted by Anson G. McCook, Secretary of the Senate, to the Secretary of the Interior:

IN THE SENATE OF THE UNITED STATES,
March 27, 1888.

Resolved, That the Secretary of the Interior is hereby directed to report to the Senate what appropriation is necessary to enable the United States Geological Survey to carry into effect the joint resolution "Directing the Secretary of the Interior by means of the Geological Survey to investigate the practicability of constructing reservoirs for the storage of water in the arid region of the United States and to report to Congress," approved March 20, 1888, and the several acts of Congress requiring such Geological Survey, under the direction of the Secretary of the Interior, to classify the public lands and furnish a map or maps showing the various divisions of the public domain suitable for agricultural, mineral and other purposes; and particularly to segregate the lands susceptible of irrigation, where irrigation is required, from other lands, and designating places for reservoirs, canals, and other hydraulic works.

Attest: ANSON G. MCCOOK,
Secretary.

On the 29th day of March this resolution was referred to the Director of the Geological Survey with the following indorsement:

DEPARTMENT OF THE INTERIOR,
March 29, 1888.

Respectfully referred to the Director of the U. S. Geological Survey for report.

WM. F. VILAS,
Secretary.

In reply I have the honor to submit the following statement:

The portion of the United States in which agriculture will be carried on only by the aid of irrigation may be broadly designated as that portion lying west of the one-hundredth meridian. Certain lands contiguous to rivers can be advantageously irrigated several degrees east of that line; and somewhat west of that line there are high plain lands to which it will not be economic to convey water,

but which will nevertheless afford a moderate return to cultivation. In the western part of Oregon and the greater part of Washington agricultural lands do not require irrigation, and there are a few other exceptional spots. The extent of the region in which agriculture depends on irrigation is about 1,300,000 square miles.

In the same region there are also great areas of mineral lands, timber lands and pasturage lands still belonging to the public domain.

The general survey, topographic and geologic, to serve as a basis for the classification of these lands, is being made by the Geological Survey with such rate of progress as appropriations permit, due consideration being had for the interests and requirements of the remaining portion of the United States to which the work of the organization has been extended by statute. The topographic work includes the indication of forested areas, and the geologic work includes the indication of mineral lands, but the discrimination of irrigable from pasturage lands requires such careful consideration of details that special local surveys are needed for this purpose.

There are certain streams which furnish more water than is needed by the lands to which they can be made tributary, and these offer relatively simple problems. Those of a second class can supply with irrigation water only a fraction of the available land, and the particular land must be selected through the weighing of considerations somewhat numerous and varied. In the third class, by far the most numerous and important, part of the land available for one stream is also available for other streams, so that a wise selection can be made only by considering a group of streams conjointly.

To determine for a given stream, or for a given group of streams treated collectively, first, the maximum area of farming land and its most advantageous selection; second, the best selection of sites for reservoirs and their proper size; and, third, the best system of headworks and canals, there are three general requisites, as follows:

(*a*) The construction of an accurate topographic map, with grade curves at such intervals as will properly represent the configuration of the ground.

(*b*) The determination of the total annual discharge of water from the catchment basin, or where there are more than one from each catchment basin, and the distribution through the year of that discharge.

(*c*) An examination of the soils in the area from which, under existing topographic conditions, the selection of land for irrigation must be made.

For the solution of the practical problems that must arise in the progress of the work thus indicated, a large body of general knowledge is necessary, a part of which is contained in existing records. Irrigation has been practiced for many centuries in Europe, Asia,

Africa and America, and has been made the subject of elaborate scientific investigation, so that the literature of the subject constitutes a large library. A second body of knowledge must be derived by the collation of the experience of irrigators and irrigation engineers in our own arid region, an experience for the most part not recorded in print. A third body of information, local as compared with foreign data, but general when considered with reference to individual streams, must be derived by direct observation and experimentation in various parts of our arid region. Some of the categories of this general knowledge may be indicated in the following manner:

(1) The rate of evaporation from the surface of water in reservoirs, canals, etc., should be determined for the different districts of the arid region and for different months.

(2) The rate of seepage from reservoirs and canals must be investigated, as well as the means by which and the extent to which it can be diminished. These factors vary greatly with different soils and with water from different sources, and can be best determined by the collation of experience, with some supplementary experimentation on existing irrigation works.

(3) The clogging of reservoirs with detritus by the streams must be investigated. It is already known that the most diverse results have been experienced with different streams, and the laws of stream action on which this diversity depends need to be developed, so as to permit their general application to the problem of the selection of reservoir sites.

(4) Experience must be collated with reference to the agricultural results obtained with irrigation from the various soils and with crops of different kinds.

(5) The "duty of water," or the area of land which may be served by a unit of water, must be determined for the various soils and crops and for the various climates involved. Under this head must be considered also the subterranean return of part of the irrigation water to the drainage channel, and its rediversion at lower levels.

(6) Consideration must be given to the washing of surplus salts from alkaline lands, as well as to the tendency to the injurious accumulation of salts in irrigated lands and the means for its prevention.

(7) In the case of long streams flowing past bodies of arable land affected by different climates, the peculiarities of climate, with especial reference to frost, must be determined.

(8) Experience must be collated with reference to the cost of construction and maintenance of reservoirs and other head-works and of canals. The experience of other lands is but partially applicable, because the cost in every case must depend upon the value of labor and the nature of the available materials.

(9) Statistics must be gathered as to the value of irrigation lands and the changes in such value depending on progressive increase in population, transportation facilities, etc.

(10) Vested rights must be considered.

Thus it is that in the selection of sites and locations for the dams, reservoirs, canals and irrigation areas, constituting together an irrigation system, account must be taken of the total volume of water susceptible of storage, of the loss through evaporation and seepage in reservoirs and canals, of the local duty of water, of the value of the redeemed land for the growth of the crops adapted to the climate and soil, of the expense for construction of irrigation works and the interest on the same, of the expense of their maintenance, of the deterioration of reservoirs by clogging with debris, and of vested rights if any exist; and all these must be considered in connection with the topographic configuration.

In view of these various considerations, and also of the importance to the agriculture of the arid region of immediate results, it is deemed desirable to organize the work, first, by undertaking immediately the local investigation of a number of drainage districts in different parts of the country where different conditions prevail; and second, by instituting a general inquiry and a general system of observations for the acquirement of the information demanded by the practical problems.

The local work for each irrigation district will consist, first, of the preparation of a topographic map with the necessary detail; second, of the examination of physical features in reference to the storage of water, and the estimation of cost and capacity of reservoirs at one or more sites; third, of the classification of the soils within the area to which the water may be diverted; and fourth, of the measurement of the water supply. The most important of these, and the one which will involve the greater part of the expense, is the construction of the map; but the measurement of the water should be begun as early as possible for the reason that the observations of at least two years are needed as groundwork for determining the extent of irrigable land and the general magnitude of the irrigation system. After the first year, gauging stations should be established in advance of other elements of local survey. At each station the rate of discharge for various water stages should be determined by measurement, and the stage of water observed daily or at short intervals during the year.

To acquire the necessary general knowledge a study should be made of the existing irrigation of the various districts of the country, attention being given to methods, costs, values, and agricultural results; and there should also be instituted at various selected points series of observations on evaporations.

With reference to the amount of money that should be appropriated to the proposed work, it is proper to take account of the magnitude

and national importance of the agricultural industry to be based on irrigation, and also of the economic loss entailed by delay.

As estimated above, the area of the arid region is about 1,300,000 square miles. Of this, about one-fifth is too rugged or too elevated to admit of cultivation under any condition of agriculture likely to arise for a century to come. A smaller fraction consists of playas, or drainless desert plains, so flat that it is impossible to wash the salts from their soils. There remain about 1,000,000 square miles of land which need only water to be rendered productive. At the minimum price of public land, $1.25 per acre, a price greater than its value for pasturage, this land has a valuation of $800,000,000 ; at $30 per acre, a moderate estimate of its value when irrigated, it would be worth $19,200,000,000. For the irrigation of this area we have the annual precipitation on 1,300,000 square miles of mountain, valley, and plain. This ranges from 5 inches or less on the dryest plains to 30 inches on the mountains, and even 75 or 100 inches on the highest peaks, and the average for the whole region is not far from 15 inches. If all this could be applied to the land suited by configuration for cultivation, it would afford about 20 inches of water annually for the whole area, or nearly double the amount which need be applied to crops during the growing season. The water which falls in the arid region would therefore fully meet the agricultural needs if only it could be stored until the proper season and then conveyed to the proper land. Unfortunately, many causes conspire to render impossible the full realization of so desirable a result.

Of the precipitation, which has the form of snow, a large fraction is returned to the air by evaporation without going through the process of melting. Of that which falls as rain a large part is received by the soil and evaporated from it without gathering in streams, and the only portion of such unconcentrated rain-fall serviceable for agriculture is that which falls on the farming land during the growing season. Of the water from rain and melted snow which gathers in channels and forms streams, only a portion has such relation to arable land that it can be utilized; the remainder flows too low, or at such distance from the land as to be beyond the economic limits of conveyance. Moreover, a comparatively small portion of the stream water is furnished during the farming season, and that which must be stored in reservoirs in order to utilize it necessarily suffers material loss by evaporation.

Under such adverse conditions it is manifest that only a small portion of the rain-fall of the region can be made to serve the farmer, and that there is no solid foundation for the opinion sometimes expressed that the greater part of our arid West will ultimately be reclaimed. In 1880 less than 1 per cent. of its arable portion had been supplied with irrigation water, and it is believed that with the most elaborate irrigation works this can not be increased to more than 20 per cent. On the other hand, an estimate based on such data as are available

leads to the anticipation that when all the larger streams have been brought under control and the storage of water has been carried as far as it may be economically there will be redeemed about 15 per cent of the region, or 150,000 square miles, comprising an area which exceeds one-half of the land now cultivated in the United States. At $30 per acre this will add $2,880,000,000 to the wealth of the nation.

The establishment of a general system of irrigation on a comprehensive plan is of immediate importance, because the agriculture of the arid region, now in its infancy, is rapidly developing, and its development without suitable regulation constantly involves the use of temporary plans which interfere with and obstruct the adoption of those necessary to the fullest utilization of resources. The most important cases of interference are those in which a large stream traversing the center of a valley receives small affluents from the lateral slopes. It is matter of experience that when irrigation is commenced without regulation the small streams, being most readily controlled, are first utilized, and their water is conveyed to low-lying land adjacent to the stream. In a comprehensive system this land is served by the water of the large stream, and the water of the small streams is used on higher-lying land, to which that of the large can not economically be conveyed. But the utilization of the small streams in connection with the low lands creates vested rights which stand in the way of subsequent regulation in the interest of the entire district.

In view of the magnitude of the interests involved, and of the great loss entailed by delay, the surveys necessary as a basis for the establishment of a comprehensive system of irrigation should be pushed with all the rapidity consistent with economy in their conduct. The Geological Survey is prepared by its organization and equipments, and by the special training of many of its engineers, to begin this work efficiently on a limited scale; but if the scale were made too great for the first year due economy could not be secured.

Impelled by these considerations I respectfully recommend that an appropriation of $250,000 be made for the first year's work, and would suggest the following clause for the appropriation bill:

For the purpose of investigating the extent to which the arid region of the United States can be redeemed by irrigation, and the segregation of the irrigable lands in such arid region, and for the selection of sites for reservoirs and other hydraulic works necessary for the storage and utilization of water for irrigation, and to make the necessary maps, including the pay of employés in field and in office, the cost of all instruments, apparatus and materials, and all other necessary expenses connected therewith, the work to be performed by the Geological Survey, under the direction of the Secretary of the Interior, the sum of two hundred and fifty thousand dollars.

I am, with great respect, your obedient servant,

J. W. POWELL,
Director.

The SECRETARY OF THE INTERIOR.

In pursuance of law the following preliminary report of the Director of the Geological Survey on the subject of irrigation was transmitted to Congress:

DEPARTMENT OF THE INTERIOR,
Washington, January 2, 1889.

SIR: In pursuance of the requirements of the act making appropriations "for the sundry civil expenses of the Government for the fiscal year ending June 30, 1889, and for other purposes," approved October 2, 1888, I have the honor herewith to transmit, to be laid before Congress, a report of the Director of the Geological Survey on the organization and prosecution of the survey of the arid lands for purposes of irrigation, and also his letter of transmittal, in which is submitted an estimate for the continuance of the work, which, with my approval, has been duly transmitted to the Secretary of the Treasury, as required by law.

In the last annual report of this Department to the President, which has already been laid before the Congress, I had the honor to submit briefly the expression of my opinion of the desirability and importance of prosecuting the investigating surveys begun under the appropriation in the act referred to, and I think the facts exhibited by the report now presented lend additional sanction to the suggestions then made. I beg leave to earnestly recommend favorable action, with a view to the early development of a scientific system of irrigation and wise legislation for the utilization of the desert lands.

Very respectfully, your obedient servant,

WM. F. VILAS,
Secretary.

The PRESIDENT PRO TEMPORE OF THE SENATE.

DEPARTMENT OF THE INTERIOR,
U. S. GEOLOGICAL SURVEY,
Washington, D. C., December 31, 1888.

SIR: In compliance with instructions I have the honor to submit herewith a report of the progress made in organizing and prosecuting the survey of the arid lands provided for by the act of Congress approved October 2, 1888.

The work has now been developed to such an extent by operations in the field that an intelligent estimate can be made of the appropriations which can be used with economy and efficiency in the prosecution of the work for another fiscal year.

In this connection it may be proper to consider the vast importance of the work to the development of the agricultural industries of the West. It will be remembered that about two-fifths of the whole area

of the United States, exclusive of Alaska, is dependent upon irrigation for its agricultural operations; that in the main it is upon these lands that the future settlers upon the public domain are to make their homes, and that already there are many thousands of people in the arid lands engaged as laborers on great farms and ranches and in mining industries and in roaming about the country prospecting for gold, silver and other minerals, and also congregated in the towns and cities that are rapidly growing throughout that country—all anxious for opportunity to settle upon the public lands and make homes for themselves. In view of these facts and of many others of equal importance, it is desirable that these irrigation surveys should be prosecuted with all the dispatch compatible with economy and accuracy.

If the work under the appropriation to be made should be commenced early in the spring and carried forward during the season of agricultural operations it would be highly advantageous. I have therefore asked that the appropriation be made immediately available.

I respectfully submit the request to the honorable the Secretary of the Interior that the following estimates for this work be transmitted to the Congress with his approval, and with it the brief preliminary report appended:

For the purpose of investigating the extent to which the arid region of the United States can be redeemed by irrigation and the segregation of the irrigable lands in such arid region, and for the selection of sites for reservoirs and other hydraulic works necessary for the storage and utilization of water for irrigation and the prevention of floods and overflows, and to make the necessary maps, including the pay of employés in field and office, the cost of all instruments, apparatus, and materials, and all other necessary expenses connected therewith, the work to be performed by the Geological Survey, under the direction of the Secretary of the Interior, the sum of $350,000, or so much thereof as may be necessary, to be immediately available.

I am, with respect, your obedient servant,

J. W. POWELL,
Director.

The SECRETARY OF THE INTERIOR.

PRELIMINARY REPORT ON THE ORGANIZATION AND PROSECUTION OF THE SURVEY OF THE ARID LANDS FOR PURPOSES OF IRRIGATION.

In the act making "appropriations for sundry civil expenses of the Government for the fiscal year ending June 30, 1889, and for other purposes," approved October 2, 1888, provision was made for the survey of the arid lands, for the purpose of redeeming the same by irrigation. The following is the text of that portion of the statute:

For the purpose of investigating the extent to which the arid region of the United States can be redeemed by irrigation and the segregation of the irrigable lands in such arid region, and for the selection of sites for reservoirs and other hydraulic

works necessary for the storage and utilization of water for irrigation and the prevention of floods and overflows, and to make the necessary maps, including the pay of employés in field and in office, the cost of all instruments, apparatus, and materials, and all other necessary expenses connected therewith, the work to be performed by the Geological Survey, under the direction of the Secretary of the Interior, the sum of one hundred thousand dollars, or so much thereof as may be necessary. And the Director of the Geological Survey, under the supervision of the Secretary of the Interior, shall make a report to Congress, on the first Monday in December of each year, showing in detail how the said money has been expended, the amount used for actual survey and engineer work in the field in locating sites for reservoirs, and an itemized account of the expenditures under this appropriation. And all the lands which may hereafter be designated or selected by such United States surveys for sites for reservoirs, ditches, or canals for irrigation purposes, and all the lands made susceptible of irrigation by such reservoirs, ditches, or canals are from this time henceforth hereby reserved from sale as the property of the United States, and shall not be subject, after the passage of this act, to entry, settlement or occupation until further provided by law: *Provided*, That the President may at any time, in his discretion, by proclamation open any portion or all of the lands reserved by this provision to settlement under the homestead laws.

In obedience to the provisions of the above statute steps were immediately taken to commence the work of an irrigation survey of the arid region of the United States. Before the passage of the act Congress had called upon the honorable the Secretary of the Interior for general plans and estimates, and under the instruction of the Secretary the Director of the Geological Survey had outlined the scope of the work and delineated in brief the results that might be expected to follow. He further made an estimate of the total cost and of the amount which it was thought could be wisely expended during the first year's operations. These reports were published by Congress, and constitute Senate Executive Documents Nos. 134 and 163, Fiftieth Congress, first session. The plan therein outlined has been followed.

TOPOGRAPHIC WORK.

The necessary topographic work was placed under the charge of A. H. Thompson. A number of topographers already employed in the Geological Survey were selected as his chief assistants, and the force was largely increased by the employment of temporary field assistants, but no increase of the permanent corps was made. Under the direction of Prof. Thompson the following-described work has been done:

WORK IN MONTANA.

Work was commenced on the Continental Divide at the headwaters of the Columbia and Missouri Rivers early in October, one party surveying on the Columbia River side and another on the Missouri River side. The whole was under the immediate charge of Mr. E. M. Douglas. An area of 2,200 square miles has been surveyed. The topographic features of this country were delineated,

the courses of the streams and the sites of all considerable bodies of water were ascertained, and the altitude, position, and general character of irrigable lands were determined. This is a region of abundant perennial streams, and many sites favorable for the establishment of storage reservoirs have been discovered.

WORK IN NEVADA.

Early in November Mr. H. M. Wilson, with the parties under his immediate charge, previously engaged on topographic work in the gold-belt region of central California, was transferred to Nevada, near the headwaters of the Truckee, Carson and Walker Rivers, and immediately began the work of an irrigation survey. This is a region where mountain waters are in great abundance, but where lands to which they can be economically conveyed are limited in extent. Up to the present time the survey of an area of about 800 square miles has been completed. Work will be continued as late into the winter as the season will permit and resumed early in the spring of 1889.

WORK IN COLORADO.

In the latter part of October, and immediately on the passage of the act, a party in charge of Mr. Anton Karl commenced work on the South Platte River. The season was too far advanced to enter the mountain region, so the survey was confined to the foot-hills and the plains extending eastward, embracing the city of Denver and a portion of the great agricultural district of Colorado. About 1,400 square miles have been surveyed.

In this region the waters of the South Platte are already employed in the irrigation of many districts, and the entire volume of the river during the irrigating season is utilized in serving the lands for agricultural purposes. The future development of agriculture in this country is dependent partly upon such an improved construction of irrigating works as will prevent waste and loss, but chiefly upon the construction of reservoirs to hold the waters which through the remainder of the year now flow to the sea without performing their duty to agriculture. The topographic work in this region is now suspended, as it can not be economically carried on in the winter, but it will be resumed in the spring.

Early in October a large party, under charge of Mr. W. D. Johnson, was sent to Colorado to operate in the valley of the Arkansas, and work is being prosecuted with vigor. An area of about 1,500 square miles has been surveyed. It embraces some regions which have already been redeemed by irrigation, but which can be further developed by better utilization of the great flow of the Upper Arkansas and by the storage of waters in the higher mountains and the foothills. The upper portion of the Arkansas, unlike that of the South Platte, is well adapted to this purpose, as there are many valleys, mo-

rainal lakes and basins that can be economically utilized for storage basins. On the South Platte much of the stored waters must be held in lakes created in the foot-hills and on the plains, while the waters of the Upper Arkansas can be held high in the mountain lands, where in many ways the conditions are more favorable and the engineering problems less difficult.

WORK IN NEW MEXICO.

At the time of the passage of the act above mentioned, parties under Mr. A. P. Davis were at work in New Mexico making topographic surveys of certain mountain regions. These surveys were on methods adapted to the purposes of the irrigation investigation, and it was therefore only necessary to enlarge the scale and extend the work into districts of irrigable lands. The entire work of the season is therefore available. The region embraced is that drained by the Jemez River and other tributaries of the Rio Grande rising in the Tewan group of mountains. The most northern river of this series is the Chama, which has its confluence with the Rio Grande above Santa Fé. The most southern is the Puerco, having its confluence with the Rio Grande below Albuquerque, and between these rivers the Jemez and other streams join the Rio Grande. At the writing of this report an area in this region has been surveyed topographically having an extent of about 6,000 square miles.

From the above it will be seen that, although the act for the irrigation survey was not signed until October, and the season favorable for surveys in middle latitude was almost past, yet the work was immediately pushed with vigor, so that at the close of the calendar year five considerable tracts of country have been surveyed—one in Montana, another in Nevada, a third in the Platte Valley of Colorado, a fourth in the Arkansas Valley of Colorado, and the fifth in the drainage basin of the Rio Grande, in New Mexico.

HYDRAULIC WORK.

As set forth in the reports made to Congress and mentioned above, an irrigation survey necessitates a hydraulic survey of a specific character.

In order to determine the amount of water which can be stored, the several streams which supply the water must be gauged—that is, their running volumes from day to day and month to month, throughout the year, must be determined Only that portion which flows during the season of irrigation can be utilized without storage. For the greater part of the year the water runs to waste if not impounded.

Again, to determine the amount of lands which can be served by the flowing water of the irrigating season and by the storage waters of the non-irrigating season, it is necessary to determine the quantity of water which should be used in serving a definite quantity of land.

This is denominated by irrigation engineers the "duty" of water. The duty of water artificially supplied is affected by the amount of rain-fall or general atmospheric precipitation, the artificially-supplied water being complementary to that. Again, it is affected by latitude, altitude and other climatic conditions. Still again, it is affected by the character of the soils. Finally, it depends largely upon the character of the crops raised.

To determine the duty of water it is necessary to resort to practical experience, and to interpret the facts of experience in the light of general climatic and soil conditions. In the storage of water, in order to determine the amount of water which can actually be conserved for useful purposes, it is necessary to ascertain the amount and rate of evaporation under different conditions of latitude, altitude and general climate. Throughout the arid region of the United States the conditions which determine the amount of evaporation are exceedingly variable, and it ranges from a probable minimum of 20 inches per year to a probable maximum of 100 inches per year. If water, therefore, be stored in artificial lakes, where evaporation is but 20 inches per year, a very small amount of water is thus lost; but if it be stored where the evaporation reaches the amount of 100 inches per year, the water lost is very great. It is necessary to determine these factors in a general way in order wisely to select the sites for reservoirs, and in order further to segregate the lands that are to be reclaimed.

All streams carry sediment, some in great quantities some in small, but when their waters are collected in reservoirs the sediment at once settles. Reservoirs, therefore, become settling basins. If the amount of sediment carried by a stream into the reservoir is very great the reservoir will be speedily filled, and in order to determine the life of the reservoir, should it never be cleared of its deposited silt, and to determine to what extent it must be purged of its sediment in order that it may permanently retain its due capacity, and further to determine the eligibility of any site and the relative values of optional sites, it is important that the amount of sediment borne by the stream shall be measured in various parts of its channel.

To ascertain the factors thus briefly set forth, the hydraulic branch of the Irrigation Survey was organized, with Capt. C. E. Dutton at its head. No permanent corps for the hydraulic survey has yet been selected, but a number of field assistants have been employed and are temporarily engaged in experimental work. At the earliest possible day the methods and instruments to be used were taken up as a subject of investigation. Many instruments and plans have been devised by engineers throughout the world, especially where irrigation is practiced, for the purpose of solving the problem of gauging rivers. These were considered, and finally a tentative selection of methods was made and the necessary instruments were procured.

In the matter of rain-gauging much is already being accomplished, as throughout the arid region the people are intensely interested in this subject, which they regard as vitally important to their industries. Many enterprising and intelligent men have instituted rain-gauge and other meteorologic observations. Similarly, various corporations have conducted inquiries of this character, and meteorologic societies have been organized in the arid States and Territories; and finally, the Signal Service of the United States is carrying forward its general system of meteorologic investigations in the arid regions. It is proposed in the irrigation survey to utilize the work of the Signal Service, the work of local societies, of State and Territorial engineers, of colleges and other corporations, and of the many individuals who have interested themselves in this subject. It is therefore believed that the needed rain-fall and meteorologic researches can be carried on at a minimum of expense, and that great practical advantage can be derived therefrom. In the selection of methods and apparatus for rain-gauging it was found that the problem had already been solved by the officers of the Signal Service, and their system was adopted.

Hydraulic engineers throughout the world have been interested in methods of determining the rate of evaporation under various conditions, and many ingenious contrivances have been used and proposed. Among these no final selection has been made, but two or three have been adopted tentatively and with modifications, and experiments have been instituted for the purpose of making a final selection of that which seems best.

The determination of the amount of sediment carried by a stream is not easy. The amount borne by suspension or flotation can be determined from day to day throughout the year with reasonable accuracy, but a large part is driven along the bottom and is never fully held in suspension. In the great arid plains and valleys of the region under consideration the amount of this driven load is comparatively greater than in humid lands, from the fact that the storm-waters in such lands excessively choke the stream-channels. In view of these facts experiments have been instituted for the purpose of developing practical methods of observation. In selecting a site for a reservoir it is incumbent upon the engineers to determine the rate at which the reservoir will probably be filled by sedimentation, and to determine, further, what hydraulic appliances and methods can be adopted to overcome this difficulty. This subject, also, is undergoing careful investigation by a number of the officers of the Geological Survey.

It will be observed that the work of the hydraulic survey consists in making a series of observations and experiments to determine the volume of water flowing in the streams, the volume of precipitation, or rain-fall and snow-fall, the rate of evaporation, or the volume of

water which will be evaporated from reservoirs of given size and situation, and the volume of silt carried by the stream; and results are obtained by continuing these observations through selected periods of time. For correct results it is necessary that the observations be made regularly and accurately; and further, that they be made systematically, in order that the records made by one person may be comparable with those made by another. To secure these results it was necessary to prepare elaborate instructions for the common use of the observers, and to prepare blanks upon which the results of observations could be recorded. With regard to stream-gauging and rain-gauging, this has been accomplished. The instructions and record forms relating to the other lines of observation are only partly completed, but will be perfected at an early day.

SEGREGATION WORK.

After the topographic and hydraulic surveys, the next step in the irrigation survey, and that which completes the work provided for in the statute, is the selection or segregation of the sites for reservoirs and other irrigating works, as diverting-dams and canals, and finally, the selection of the lands that can be most economically served. For this branch of the work no scientific organization has yet been made, nor has a chief been selected into whose hands the work shall be consigned, but the general subject is one to which the Director of the Survey has been giving careful attention, in which he has received the assistance of a number of his colleagues, and concerning which he has sought and obtained the advice of many of the leading engineers of the country.

RESERVOIR SITES.

In the selection of reservoir sites a number of important conditions, each one of which is vital to the best success, have to be considered. The basin selected must be such as will store the greatest amount of water with the greatest economy of construction. It is manifest that, as reservoirs can not be excavated within reasonable conditions of cost, they must be natural basins. In many cases these will be existing lakes, and while many such will require dams at their outlets in order to regulate by gates the outflow of the water, there are some which can be controlled by tapping below the level of the natural discharge. Such reservoirs will be the most economical, as outlets only will have to be constructed and guarded with gate-ways, and the natural evaporation surface will not be enlarged.

A great number of these natural reservoirs have already come under the observation of the officers of the Survey. As an illustration, Lake Tahoe, which is the source of the Truckee River, may be cited. This is a lake filled from a catchment basin of 500 square

miles, and having a surface of 195 square miles. This storage lake, constructed by nature, has only to be tapped and gate-ways constructed and it can at once be used, and the water which is gathered through the non-irrigating season may through the irrigating season be discharged again into the natural channel in addition to the waters which fall from the heavens during that season, and the whole, carried down to the diverting-dams in the valley below, turned out into irrigating-canals, to be spread over the land.

In the total area available for irrigation to which the water of the Truckee may be carried it is probable that an acre foot of water, that is, an acre of water 1 foot deep, will abundantly irrigate an acre of land through one season; and it is possible to store in Lake Tahoe 500,000 acre feet, which can be made to irrigate 500,000 acres of land. This can be done by providing for the discharge of 4 feet of water from the surface of the lake through each irrigating season, and providing for the conservation of the same amount annually contributed by the clouds. The survey has not yet proceeded far enough to determine where these lands can be selected; the case has been here cited simply as an illustration of the manner in which the natural lakes of the mountain regions of the arid land can be economically utilized as storage reservoirs. Such lakes exist in great numbers; altogether there are several hundred, each one of which must be examined and carefully surveyed in order to determine the methods by which it can be used.

In addition to the natural lakes to be thus employed a great number of artificial lakes must be created, and as far as possible these lake sites should be selected in elevated mountain regions. A variety of conditions conspire to determine this preference. First, in the high mountain regions evaporation is at a minimum, and the least amount of water will be lost by this means where the lakes are at great elevation. Second, the mountain waters are comparatively pure, and hence the mountain reservoirs will be filled by sediment to the smallest degree. Third, the lands to be condemned for this purpose will be above the agricultural limit, and therefore can not be utilized for any purpose other than that of brief summer pasturage. Fourth, the waters thus retained can be restored to their natural channels and be distributed to all the communities settled in the valley below whose industries are dependent upon irrigation. Fifth, such reservoirs are effectually removed from positions where they threaten danger to homes and lands if by reason of bad construction or neglect they are permitted to breach their retaining-walls.

But while a large part of the rain-fall is concentrated in these elevated regions it is not all found there; the low mountains and foot-hills are also regions of great precipitation, and midland reservoirs are necessary to conserve all the water. To a large extent these will have to be constructed in the foot-hills. They will usually be of

smaller extent than those of the highlands, though notable exceptions to this general rule are already known.

And finally, great reservoirs or artificial lakes will have to be established along the plains and in great valleys not far from the mountains. Natural morainal basins can often be discovered, and valleys of small lateral streams can be utilized by constructing dams along their lower courses where favorable conditions exist. These reservoirs will usually have a greater area as compared with their depth than those of mountains, and, being in regions of greater evaporation, the waters stored therein will sustain great loss. They are to be considered only as necessary and important auxiliaries to the general reservoir system. But there are districts of country where the mountains rise precipitously from plains or valleys to the crests of the ranges, where mountain meadows, parks, and natural lakes are few, and where the principal storage must be in the lowland reservoirs. As already stated, the waters of the North Platte and of the Arkansas can be mainly stored in the highlands, while the water of the South Platte must be chiefly stored in the lowlands.

IRRIGABLE LANDS.

In the selection of irrigable lands many important considerations are involved, some of which are as follows:

The lands selected should be in a situation where the waters for their fertilization can be delivered at a minimum of expense. To secure this, sites for diverting-dams must be chosen where permanent dams can be constructed, and where they will not be subject to destruction through yielding foundations and by great floods. In the region of country where irrigation is already practiced in the United States this maxim has been neglected by reason of the want of proper information, and great losses have resulted. Again, the sites of the canals for carrying the waters must be on lands where the loss by seepage and evaporation is little, and where the country through which they are to be constructed is of such a nature that they will not be in danger of destruction from storm-waters. These conditions are primary in the establishment of the fundamental works of irrigation. There are certain other conditions, secondary to them, which need not be enumerated here. All together they constitute the engineering conditions affecting the selection of lands to be irrigated.

As the amount of eligible land will generally be found to be largely in excess of the amount which can be served by the waters, judgment must be exercised in the selection of the lands most available and valuable for agricultural purposes. Having found where waters can be economically carried, the first set of conditions to influence the selection of the land may be considered under the general head of altitude. The higher the selected lands are and the nearer they

are to the source of the water the shorter will be the canals; on the other hand, the higher the lands the more inhospitable will be the climate. In the first place, no lands should be selected at an altitude where profitable agriculture can not be carried on. This rule excludes the elevated lands of many great mountain meadows and parks. Below this elevated zone is a wide range of selection, governed by a wide range of varying and competing conditions. The higher the lands are the greater will be the duty of water, as the regions are more humid and a smaller amount of water is necessary for their reclamation, while a smaller amount is lost in the process of transportation. This, together with the condition mentioned above, namely, that of shorter canals, leads to the selection of lands in the upper portions of the valleys and along the plains near to the foot-hills.

On the other hand, in the country farther down the valleys and farther away from the mountains the climate is warmer, vegetation grows with greater luxuriance, the harvests are more abundant, a greater variety of agricultural crops can be raised, and the season of agricultural operations is greatly lengthened. In a general way it may be stated that a difference of 600 feet of altitude is equivalent to a difference of about 1 degree of latitude. These considerations tend toward the selection of lands in the lower regions. Perhaps the attractions to the lower lands are about equivalent to the attractions to the upper lands, and if no other conditions were involved the widest latitude in selection might be permitted; but there are other conditions of profound importance.

The river channels of the arid region of the United States have characteristics which potently affect the interests of irrigation and the problems involved in the selection of irrigable lands. The streams all have their sources in the mountains, where there is great rain-fall, and they descend with rapidity by steep declivities into the plains and valleys below, where the channel grades are greatly reduced, and where the arid regions proper are situated and the agricultural lands are found. When the rivers reach the low, comparatively arid lands, their characteristics suddenly change; they no longer run in deep canyons or narrow valleys, but find their way through broad and shallow valleys, and the agricultural lands rise from these low valleys on either side by steps or terraces, and bench lands are found. Within the broad valleys the streams are wide and shallow. Between the width and depth of their channels there is a very large ratio; a stream a hundred yards wide may be but a few inches deep, and a stream a thousand yards in width may have an average depth of but a yard or even a half yard.

Again, in the plain and valley reaches of the rivers the country on either side is so arid that few or no perennial streams are produced;

that is, the principal rivers have no prairie and plain-born affluents that run throughout the year. Yet storms fall on these lowlands, and the storm waters are gathered into the principal rivers and carry on their floods vast loads of dust and sand which are deposited in the channels of the rivers and keep them forever choked with mud. It is thus that mountain torrents of clear water are suddenly transformed into rivers of mud when they pass to the plains and valleys. The importance of these factors to the problems of irrigation is enormous. The rivers choked with mud can not flow freely to the sea, but are spread out over broad surfaces and absorbed in the sands, and their waters are evaporated, so that but a small proportion of the outflow from the mountains finds its way to the sea. There are many creeks and rivers that are wholly absorbed in this manner; instead of emptying into the ocean they empty into arid sands and dust plains and are lost. It is often the case with a stream that while it might be made to irrigate a tract of 10,000 acres, or even 100,000 acres, at the point where it leaves the mountain, yet it is entirely lost as it advances, so that no irrigable lands can be redeemed by it at a distance of 25 or 50 miles away.

But besides the loss of waters in the process of their transportation along natural channels, there is another condition of importance. In the valley and plain regions the streams are loaded with mud and sand, and when the current is checked by the diversion of the water into canals of gentle inclination this sediment is thrown down, and its volume is so great that it speedily fills and obstructs the irrigating channels, and is injurious to the land over which it is poured.

It will be seen, therefore, from the explanation which has been given, that it will usually be advantageous to take the waters from their natural channels before they are spread into the shallow channels of the lowland regions and loaded with mud. And the problem practically takes this form: Is it better to select elevated lands and serve them through short canals, or to select lower lands and serve them through longer canals? It is probable that in most cases this problem will be solved by a consideration of the character of the topography and of the soils.

APPROPRIATION OF RESERVOIR SITES.

I respectfully invite your attention to the clause of the act providing for an irrigation survey which withdraws from "sale, entry, settlement or occupation" the lands selected for reservoir sites and those segregated as irrigable tracts. It is as follows:

> And all the lands which may hereafter be designated or selected by such United States surveys for sites for reservoirs, ditches or canals for irrigation purposes, and all the lands made susceptible of irrigation by such reservoirs, ditches or canals are from this time henceforth hereby reserved from sale as the property of the United States, and shall not be subject after the passage of this act to entry, settlement or

occupation until further provided by law: *Provided*, That the President may at any time, in his discretion, by proclamation open any portion or all of the lands reserved by this provision to settlement under the homestead laws.

It is apparent that the reservation from sale of the lands necessary for the sites of reservoirs is eminently wise, as no restriction or burden should be placed upon the development of agriculture by irrigation in the arid lands, but some provision should be made by which such reservoir sites can be promptly utilized for the purposes for which they are designed. It is shown that further legislation is contemplated from the fact that the reservation is made to extend only "until further provided by law." In some of the States of the arid region there are already statutes providing for the occupation and utilization of reservoir sites. Perhaps the streams, not being navigable waters, are under the control of the States, but the lands to be covered by waters in the reservoir system largely and chiefly belong to the General Government. If these assumptions are correct there is a divided jurisdiction, as the control of the waters belongs to the State and the control of the lands belongs to the General Government. It is suggested that under these circumstances it may be wise to cede the lands reserved for reservoir sites to the several States and Territories under conditions and restrictions that will secure their utilization for the purpose designed, and to prevent their becoming the property of individuals or corporations and thus assuming the form of monopolies.

DISPOSAL OF IRRIGABLE LANDS.

The propriety of reserving the irrigable lands from sale, settlement and occupation until restored under the homestead laws through proclamation of the President, is worthy of further consideration. If the selections are wisely made—and this must be assumed—the best lands, all things considered, that belong to the valley or plain of a given stream are segregated from the general domain and peculiar restrictions are placed upon their disposal; that is, they can be settled only under the homestead provisions, and that after proclamation by the President, while titles to the other lands can be secured under the homestead laws, the pre-emption laws, the desert-land laws and the timber-culture laws.

The individual wishing to obtain titles to lands will prefer to take up lands under the more liberal provisions, so that the selected lands will be neglected and the non-selected lands will be entered; and as the statute now stands the waters of the streams will be taken to the non-selected or poorer lands. It must in this connection be further understood that the difference between the good and the bad lands will usually be very great. It may often be the case that the water necessary to irrigate a square mile of the poorer non-selected lands would, if taken to the selected lands, irrigate 2, 3, 4, 5, or more square

miles. The individual making the selections can not be supposed to have the general good in view, but only his personal interests, and he will not consider the facts here presented.

Under these circumstances it would seem wise either to provide that the waters of the streams and reservoirs shall belong to the segregated lands, or to repeal the clause which provides that they can be settled only under the homestead laws. The effect of this last provision would be to make the ultimate choice of the lands optional with the settler in each case, and the value of the official selection would be in giving to the settler the necessary information upon which his judgment could be formed. Again, it might be wise to temporarily suspend or permanently repeal the laws providing for the disposal of the arid lands—homestead laws, pre-emption laws, desert-land laws and timber-culture laws—and provide a new statute adapted to the conditions now prevailing. Again, it might be wise to repeal the pre-emption laws, the desert-land laws, and the timber-culture laws in their application to the arid lands, and to let the homestead laws remain, to be improved from time to time as circumstances demand.

With a degree of misgiving the Director begs permission to suggest as his own opinion that the best solution of the problem under the present circumstances is to withdraw all the lands of the arid region from "sale, entry, settlement or occupation," except those selected as irrigable lands, and to allow titles to irrigable lands to be acquired only through the operation of the homestead laws and the desert-land laws.

These suggestions as to legislation may be altogether unwise, but the problem of the best disposition to be made of the arid lands remains. It is a problem of profound importance, and it presses for solution. Many thousands of persons are already in that country and eagerly desirous of establishing homes for themselves, and they are debarred therefrom because the land system which now exists, a system which was the growth of time, and to which the highest statesmanship had been devoted for a long term of years, was adapted to the physical conditions which prevail in humid lands, and is not adapted to the conditions which prevail in arid lands. The march of settlement in its progress westward has reached a region of country where the physical conditions and limitations of agriculture differ altogether from those prevailing in the regions first settled, and problems are presented new to us and unknown to our ancestors, who came from northern Europe, but very old to the people of southern Europe and of other regions of the earth. In fact, the earliest agriculture known to the world was that which was carried on by means of irrigation.

It is due from me to recognize the valuable services of Professor Thompson and Captain Dutton, who have with great energy and vigor assisted me in organizing and starting the Irrigation Survey.

Both of these gentlemen have had long experience in kindred work of the Geological Survey, and have studied the special problems of irrigation for many years, and they were therefore eminently qualified by scholarship and practical experience to execute the task. In like manner all of the topographers and hydrographers who have been engaged in the work have exhibited enthusiasm and efficiency.

PURPOSE OF THE SURVEY.

From a consideration of the statutes thus enumerated and the executive correspondence preliminary thereto, and from an examination of the reports made by committees of the Congress and the Congressional debates on the subject, it seemed clear to the Director that it was not the purpose of the Congress to create a survey as a preliminary step to the construction of works of irrigation by the General Government. From these sources it was abundantly manifest that the object of the survey should be to collect facts necessary to intelligent legislation relating to the public domain and to wise administration of the laws relating to its disposal in small parcels to the people, and at the same time to furnish needed information to the agriculturists rapidly settling in the arid lands. The information needed by the Congress and by the executive departments of the Government may be briefly characterized in the following manner:

In the arid lands, where agriculture is dependent upon irrigation, only a small area can be redeemed, as the waters are insufficient to serve all of the lands. The lands vary in quality from worthless mountain slopes and lava fields to smooth and rich plains. Out of these lands of variable quality the best should be selected in the interest of the future agriculture of the country.

The chief precipitation of moisture in the arid land is on and about the mountains, where the rain-fall is great, and it becomes less, other things being equal, with distance from these centers of precipitation. It is thus that the mountain regions are the catchment areas for distant valleys and plains; and an agricultual district below, where the industry may be successful and profitable, depends upon the catchment area above.

Catchment areas and farming areas are thus interdependent, though separate. The farming interests on the irrigable lands of the plains and valleys must, somehow or other, be able to protect the catchment areas on which their agriculture depends.

The waters of the springs flow into creeks, and the creeks into smaller rivers, and these into the great rivers which ultimately flow to the sea. In the main these are the waters to be used in agriculture, and by some means they must be divided between the different agricultural districts. It is possible to relegate waters to lands in the mountain regions where the climate and soil conditions are unfavorable to agriculture, and this is being done to a large extent at the present time, greatly to the disadvantage of the agricultural interests of the region. It is also possible to relegate the waters to lands too far away from the source of water supply, so that they are largely lost in the sands of the river valleys through which they pass. Under such conditions only very small regions can be cultivated and the waters are chiefly wasted. For example, it is possible to select lands low down on a given stream where the waters would be sufficient to irrigate only 100,000 acres. But if the same stream could be taken out on lands one or two hundred miles farther up, the waters would be sufficient to irrigate one or two million acres of land. This wasteful use of water by selecting lands too far down the stream is in progress and needs correction.

The controlling agricultural value in arid lands inheres in the water, as the land is in excess of the water, and for the interest of agriculture waters as well as lands must be divided and distributed to the people. As the system is in progress, in general the lowest lands are taken first. Gradually higher and still higher lands are taken. Those who go above can easily take the water from those who are below. The industries on the lower lands are therefore created only to be ultimately destroyed. This condition of affairs has already been reached on many rivers, and it is in this manner that the agriculture is being driven to the mountains. Only the farmers in the mountains are secure, for they are the only persons from whom the waters can not be taken away. It thus happens

that district is in conflict with district, and these conflicts must, somehow or other, be settled, and future conflicts should be avoided.

Many of the rivers on which the agricultural lands depend cross State lines, and State is in conflict with State, the lower States protesting against the abstraction of their waters by the States above. These conflicts have become bitter and are likely to lead to serious interstate difficulties.

Some of the rivers flow part way in the territory of the United States and part way in the territory of other nations—in the British possessions at the north and the possessions of the Republic of Mexico at the south, and international problems have already arisen, and in the future they will arise in great magnitude.

To settle these international problems, interstate problems, and inter-district problems, all of the facts must be collected and set forth to the Government of the United States, which is the custodian of the public domain, the agency for the settlement of international disputes, and the authority for the settlement of interstate disputes.

By unregulated and improvident disposal of lands and water rights the General Government is gradually getting into unfortunate relations with the agriculturists of many districts of country. It is disposing of irrigable lands to individuals by homestead settlement, pre-emption settlement, timber-culture privileges, and desert-land methods, and requiring people to irrigate their lands as a part of the contract by which the title to the lands passes from the Government to the individual. When these people have thus acquired title to their lands by processes of irrigation required of them by the statutes, they will in many instances be unable to sustain their rights to the use of the water on the lands which they have selected and redeemed, because other persons will have acquired similar rights to other lands above. To protect those above is to destroy those below; to protect those below is to destroy those above. One party must have its values destroyed, and that party will expect reimbursement for lost values from the General Government. These claims are already appearing in Congress, and in the near

future they will appear in large numbers, involving many millions of dollars. The real problem for Congress to solve is this: How can the waters and lands of the arid region be distributed to the people in such a manner that the waters and lands can be used to the best advantage for all the people; that no agricultural industries may be developed on lands where they can not be maintained, and that inter-district, interstate, and international conflicts may be avoided? The interests involved are of great magnitude. It is possible by the neglect of wise prevision to doom the development of the agriculture of the arid lands to a comparatively small area in the aggregate, or by wise prevision to provide for the development of a comparatively large area. Between the minimum and maximum possibilities there is a wide difference, the one being two or three fold that of the other. Under the best conditions an area of more than 100,000,000 acres can be redeemed by the use of the streams, while by the most unfavorable conditions from 30,000,000 to 40,000,000 acres only can be redeemed.

The information necessary for the people may be briefly characterized in the following manner: The people should be able to discover what lands can be permanently irrigated, in order that they may occupy them and make their homes thereon, and not make settlements where they must ultimately be abandoned. The people should know definitely and specifically what waters they may be entitled to for irrigation, and that their rights can not be impaired except by acts of their own. The people settling upon the lands should be informed of the catchment areas of the waters which they use in agriculture, in order to protect them. These catchment areas are, in the main, mountain forest lands, and on the preservation of these forest lands the agriculture below depends to an important extent. The people should be informed of the manner by which the waters of the streams can be brought to their lands, and how the waters which usually run to waste during the non-irrigating season may be stored in reservoirs to await the time of growing crops when they are needed. These are facts which the settlers—the farmers who develop the country and carry on the agricultural industries—can not obtain for themselves.

There is another reason for the survey, plainly expressed in the statute and existing in the conditions under which the agriculture of the arid region may be controlled. The statute provides for the selection and permanent reservation of dam sites, canal sites, and reservoir sites, in order that they may not fall into the hands of individuals and corporations for speculative purposes, and that they may be held in the hands of the General Government in trust for the use of the people.

It is thus that the Director interprets the purpose of the organic law of the Irrigation Survey: that it is the function of the Survey to collect information for the General Government, which is the present custodian of the values involved and the guardian of international and interstate rights, and to collect information for the people who have already settled on the lands and are to occupy them in the future, and to preserve great rights and values for the use of the people at large. How it is proposed to perform these functions will be briefly set forth.

PLAN OF THE SURVEY.

The work of the Irrigation Survey is naturally divided into three parts, topographic, hydraulic, and the planning of works. These are very distinct branches of engineering. The work is naturally divided in the field in this manner, and a distinct party must be organized to carry on each part; and it is manifestly economic and in the interest of good work that men trained in the special work of each department should be employed in that department, as by such a division of labor the greatest skill can be brought to bear upon the several problems and the best results obtained. The topographic work is the basis of the survey and it does not differ in any material respect from that necessary for the Geological Survey. Its function is that of discovery, for it reveals the most important facts necessary for the planning of a system of irrigation works. The principal facts may be enumerated as follows:

Under the statute it is necessary to segregate the irrigable lands. In almost every valley of the arid region there is more irrigable land than the waters are able to serve, and it becomes

necessary in making the selection to choose the best lands and those that can be most economically served by the waters. A topographic survey reveals all the essential facts necessary for wise selection, and collects and assembles the facts in the cheapest and most thorough manner. The statute also provides for the segregation of reservoir sites. To carry out this provision of the law it is necessary that the reservoir sites should be discovered. The most important reservoir sites are found in mountains; some are found in the foot-hills and others in the valleys and plains below. Whenever it is possible reservoir sites are not selected along the course of streams, but in lateral depressions, especially in the foot-hills, valleys, and plains. To discover these sites the entire region must be reviewed instrumentally, and this is a topographic survey in all its elements. The construction of the maps by the draughtsmen after the facts are known is the cheapest, simplest, and most efficient manner of assembling the facts to be used.

Having discovered reservoir sites and irrigable lands, it becomes necessary to discover canal sites of two classes: first, those by which the waters can be delivered from the streams to the reservoirs; and, second, those by which the waters are to be delivered from the reservoirs to the lands. These canal sites must be discovered in connection with the reservoir sites themselves and must be related to them, and the selection of the reservoir sites must sometimes be governed by canal conditions, for a good reservoir site may not always be situated in such a position that waters can be cheaply delivered to it and from it. In any district of country, the irrigation of which is to be planned, it becomes necessary to discover all diverting dam sites on the stream, all possible reservoir sites, and all possible canal sites connecting the diverting dam with the reservoirs and connecting the reservoirs with the lands, in order that the cheapest and best system can be planned. All of these facts are revealed in the simplest and the cheapest manner by a topographic survey; in fact, they can not be properly collected in any other manner.

The most important part of the hydraulic survey relates to the measurement of water supply. The statute directly pro-

vides that the survey shall determine to what extent the arid region can be redeemed by irrigation, but the same problem is involved in planning the irrigation works and making the segregations which the statute directs. To carry out these provisions of the law it becomes necessary to discover what waters can be used for irrigation and how much water is necessary for irrigation. The gauging of all the streams of the arid region by current meters and nilometers, or river-height gauges, would be enormously expensive and require a long period of time. A more practical, accurate and economic system is possible, which may be briefly described as follows: The several drainage areas, which in the aggregate amount to all of the country surveyed, may be determined. A region like that drained by some great rivers, as the Missouri, the Yellowstone, the Platte, the Arkansas, or the Rio Grande, may be determined in the following manner: Its several catchment areas, which must be considered independently in planning a system of works, can all be determined, and one or more typical streams in one or more of these several catchment areas may be gauged, and with the data thus obtained—and certain other data, which need not for this brief discussion be explained—the water supply of the several drainage areas may be discovered. But there are two factors of importance to the hydrographer in measuring a drainage basin: First, the entire horizontal area must be known with reasonable accuracy, for that is the whole surface presented to the clouds as a catchment district. But this fails to meet all the wants. The declivities must be determined.

If the country is flat, and covered with sands and loose material—as flat countries usually are—the rains fall upon it and are absorbed and reevaporated; but as the declivities increase, more water flows into the channels. In the arid lands under investigation the two extremes of this condition are found. In some regions the lands are so flat and sandy that no waters are collected in the principal streams; all of the rain-fall is absorbed and evaporated. In other regions the declivities are so great and the surfaces are composed so largely of naked, solid rock, that almost the entire rain-fall is gathered into chan-

nels. It therefore becomes necessary to determine the areas and declivities of catchment basins. All portions of the arid region constitute parts of one or another drainage basin. It therefore becomes necessary to determine the areas and declivities of the entire country. This is the topographic survey as described above. Such survey, therefore, has a double purpose, namely, that required by the statutes in making the selection of dam sites, canal sites, reservoir sites, and irrigable lands, and that required by the hydraulic survey in determining the amount of water which can be used in irrigation and the amount which the canals will be required to carry and the amount which the reservoirs will be required to hold. The topographic survey is therefore the basis of all the work.

The work of the hydrographic survey consists of the following principal elements: First, the gauging of typical streams. Second, the gathering of rain-gauge records from the people who are interested in the subject and who in the aggregate make such observations on an elaborate scale. In some few cases these rain-gauge records are supplemented by records kept by the hydrographers. By the topographic survey the areas and declivities of catchment basins are determined; by the rain-gauging records the rain-fall is determined; by the stream-gauging operations the flow of typical streams from known areas and declivities with known rain-fall is determined. Having thus obtained the run-off from typical areas, we are able to compute the run-off from each and all of the areas in a manner sufficiently accurate for the purpose in view. Third, the determination of the amount of evaporation from reservoir surfaces under varying climatic conditions; and this is necessary in order that the waste from the reservoirs from this source may be determined. Fourth, to measure and compute the amount of sediment carried by the streams. This is necessary to determine the life of the reservoirs, or the length of time it will require to silt them full if methods to relieve them of sediment are not used. Fifth, to determine the duty of water, that is, the amount of water which is necessary to irrigate an acre of land under the varying conditions presented in the arid region.

It will thus be seen that the topographic work is preliminary to the hydrographic work and to the engineering work. The hydrographic work is also preliminary to the engineering work, which is now to be described.

The duties of the officers of the engineering branch of the Survey are, to select from all of the discovered dam sites the best; to select from all of the discovered reservoir sites the best; to select from all of the canal sites the best; and to select from all of the irrigable lands the best tracts. Having made these selections for any basin, they have by that process planned a system of irrigation. It is now their duty to determine its cost. For this purpose they examine with care the special diverting dam sites and plan the works and determine the elements of cost quantitatively; that is, the length, height, width and slopes of the dam, the amount of material which must enter into its construction and the availability of that material, and the amount of labor necessary to complete the work. In the same manner they examine the sites of the reservoirs minutely and furnish plans and costs of the same. They also survey on the ground the canal lines which have been selected, determine the necessary capacity of the canals and their gradients, find how much cutting and filling must be done, and discover the cost of all the work. They then discover, in a more minute way, by township and section, or by Land-Office designations, the specific tracts which can be irrigated under the system. Finally, all of the facts discovered by the topographic, hydrographic and construction engineers are assembled on maps, plans, sections and other diagrams, with tables and explanatory text, to be reported to the Congress and especially to the people of the arid regions.

It is proposed to set forth in a brief way the manner in which the above plan of work has been inaugurated.

As the appropriation for the Irrigation Survey for the fiscal year ending June 30, 1890, was made available upon the passage of the act, it was decided to inaugurate the work in the spring; and this was highly advantageous, as it enabled the survey to be prosecuted during the season of irrigation, when the problems involved could be studied to the best advantage.

The Director therefore prepared a general plan for the commencement of operations and submitted the same to the honorable the Secretary of the Interior for his approval, which it received. The following is the plan submitted:

DETAILS OF THE PLAN OF OPERATIONS.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., May 18, 1889.

The SECRETARY OF THE INTERIOR:

SIR: I have the honor to submit the following plan for the operations of the irrigation survey of the arid lands.

The survey was commenced in the fall of 1888, under the authority of the statute approved October 2, 1888, as follows:

For the purpose of investigating the extent to which the arid region of the United States can be redeemed by irrigation, and the segregation of the irrigable lands in such arid region, and for the selection of sites for reservoirs and other hydraulic works necessary for the storage and utilization of water for irrigation, and the prevention of floods and overflows, and to make the necessary maps, including the pay of employés in field and in office, the cost of all instruments, apparatus and materials, and all other necessary expenses connected therewith, the work to be performed by the Geological Survey, under the direction of the Secretary of the Interior, the sum of one hundred thousand dollars, or so much thereof as may be necessary. And the Director of the Geological Survey, under the supervision of the Secretary of the Interior, shall make a report to Congress on the first Monday in December of each year, showing in detail how the said money has been expended, the amount used for actual survey and engineer work in the field in locating sites for reservoirs, and an itemized account of the expenditures under this appropriation. And all the lands which may hereafter be designated or selected by such United States surveys for sites for reservoirs, ditches, or canals for irrigation purposes, and all the lands made susceptible of irrigation by such reservoirs, ditches or canals are from this time henceforth hereby reserved from sale as the property of the United States, and shall not be subject after the passage of this act to entry, settlement or occupation until further provided by law. *Provided*, That the President may at any time in his discretion by proclamation open any portion or all of the lands reserved by this provision to settlement under the homestead laws. (Vide Statutes of the United States of America, passed at the first session of the Fiftieth Congress, 1887–1888, pp. 526–527.)

Under the above statute the work has been organized and continued to the present time. The following is a plan for the continuation of the work as provided for by the statute approved March 2, 1889:

Irrigation Survey: For the purpose of investigating the extent to which the arid region of the United States can be redeemed by irrigation and the segregation of irrigable lands in such arid region, and for the selection of sites for reservoirs and other hydraulic works necessary for the storage and utilization of water for irrigation, and for ascertaining the cost thereof, and the prevention of floods and over-

flows, and to make the necessary maps, including the pay of employés in field and in office, the cost of all instruments, apparatus, and materials, and all other necessary expenses connected therewith, the work to be performed by the Geological Survey under the direction of the Secretary of the Interior, two hundred and fifty thousand dollars, of which sum fifty thousand dollars shall be immediately available, and the Director of the Geological Survey, under the supervision of the Secretary of the Interior, shall make a report to Congress on the first Monday in December of each year, showing in detail how the said money has been expended, the amount used for actual survey and engineering work in the field in locating sites for reservoirs, and an itemized account of the expenditures under this and any future appropriation. (Vide Statutes of the United States of America, passed at the second session of the Fiftieth Congress, 1888–1889, pp. 960–961.)

The work in this survey is properly divided into three parts, namely:

I. The Topographic Survey.
II. The Hydraulic Survey.
III. The Engineering Survey.

It is recommended that work be prosecuted in Montana, Colorado, New Mexico, Idaho, Nevada and California.

The appropriation is inadequate to operate economically in all of the States and Territories where arid lands exist, and hence where agriculture is dependent on irrigation. It therefore became necessary on the inauguration of the work to make selections. The choice made has been governed in the main by the following considerations.

It seems desirable to present some finished work to Congress at the earliest possible date, and for this reason regions have been selected where topographic maps were already finished or in process of construction, and where rivers had already been gauged and their volumes approximately determined.

It also seems desirable to select as far as possible regions of country already well settled, and where the problems presented were pressing for speedy solution. It should be noticed that this last consideration compels the Survey to attack the most difficult problems first, a condition in some respects unfortunate.

In order to set forth the purposes and methods of the Irrigation Survey, I beg permission to refer the Secretary to accompanying documents, namely:

(1) Letter from the Secretary of the Interior, transmitting, in response to Senate resolution of February 13, 1888, report concerning the irrigation of certain lands.

(2) Letter from the Secretary of the Interior, transmitting, in response to Senate resolution of March 27, 1888, report relative to the reservoirs for the storage of water in the arid regions of the United States.

(3) Letter from the Secretary of the Interior, transmitting, in pursuance of law, report of the Geological Survey on the subject of irrigation.

TOPOGRAPHIC OPERATIONS.

It is proposed to continue the topographic work under the general supervision of Mr. A. H. Thompson.

MONTANA.

That the work in Montana be extended eastward from the 100th meridian along the valley of the Yellowstone River, including atlas-sheets, long. 109° 00′, lat. 45° 30′, and long. 109° 30′, lat. 45° 30′, an approximate area of 2,000 square miles.

That the organization to complete this work consist of two topographic parties, under the supervision of Mr. Frank Tweedy, with Mr. Jeremiah Ahern as assistant.

That each topographic party consist of a chief, two field assistants, two packers or teamsters, and one cook.

That the field-work be done on a scale of 1 inch to 1 mile, and with sufficient detail to construct a map on the scale of 1 inch to 2 miles, in contours having intervals in the valleys of 20 feet and in the rougher country of 50 and 100 feet.

That these parties commence field-work about May 15 and continue until October 15.

ESTIMATE OF EXPENSES.

For two topographic parties: two chiefs and two permanent assistants, work to commence May 15 and continue five months in the season of 1889 and one month in the season of 1890, area 2,000 square miles..... $7,000

COLORADO.

That the area to be surveyed in Colorado be that included in the drainage basin of the Arkansas River as far east as the 102d meridian or such portions as are now unmapped, an approximate area of 28,000 square miles. The field-work to be done on a scale of 1 inch to 1 mile, and in sufficient detail to construct maps on the scale of 1 inch to 2 miles, in contours having intervals of 20 feet in the plains region and the mountain valleys, 50 feet in foothills, and 100 feet in higher regions. That the organization to perform this work consist of one triangulation and supervision and four topographic parties, with such other smaller organizations as may be necessary, the whole to be under the immediate charge of Mr. Willard D. Johnson, with Messrs. C. H. Fitch, Morris Bien, John W. Hays, and R. C. McKinney as assistants in charge of parties. The triangulation party to be organized with Mr. Johnson as chief, and to consist, besides himself, of one field assistant, two teamsters and one cook. The topographic parties to consist, besides the chief, of from two to four field assistants, one teamster, and one to three cooks, as the exigencies of the work demand. These parties to take the field in May and continue work until late in October.

ESTIMATE OF EXPENSES.

For one triangulation and four topographic parties: five chiefs of parties and ten permanent assistants; work to commence in May, and continue five months in the season of 1889 and two months in the season of 1890; area 28,000 square miles. $37,000

NEW MEXICO.

That the work be prosecuted in New Mexico in the drainage basins of the Rio Grande and Chama Rivers, including atlas-sheets, long. 106° 00′ lat. 36° 00′, long. 106° 30′ lat. 36° 00′, long. 106° 30′ lat. 36° 30′, in all an area of approximately 3,000 square miles.

That the organization to complete this work consist of one triangulation and supervision and two topographic parties, all under charge of Mr. Arthur P. Davis, with Mr. R. Henry Phillips as assistant. That the triangulation and supervision party consist of Mr. Davis as chief, one assistant, two packers, and one cook. That each topographic party consist, besides its chief, of two field assistants, two teamsters and one cook.

That field-work be done on a scale of 1 inch to 1 mile, and with sufficient detail to construct a map on a scale of 1 inch to 2 miles, in contours having intervals in the valleys of 20 feet, and in the mountainous country of 50 or 100 feet as the grade of slope demands.

That field-work commence about June 15 and continue until October 15.

ESTIMATE OF EXPENSES.

For one triangulation and two topographic parties: three chiefs and three permanent assistants; work to commence June 15 and continue four months in the season of 1889, and one month in the season of 1890; area 3,000 square miles..... $15,000

IDAHO.

That work be carried on in the valley of the Snake River, starting from the vicinity of Boisé City and working east on atlas-sheets, long. 115° 00′ lat. 43° 00′, long. 114° 30′ lat. 43° 00′, and long. 114° 00′ lat. 43° 00′.

The field-work to be on a scale of 1 inch to 1 mile, and in sufficient detail to construct maps on a scale of 1 inch to 2 miles, in contours having intervals of 20 to 100 feet, as the character of the relief of the country demands; that an area of approximately 3,000 square miles be surveyed, the organization to do this work to consist of two topographic parties under immediate charge of Mr. William T. Griswold, with Mr. E. T. Perkins as assistant. These parties to comprise, besides the persons in charge, two field assistants, two teamsters, and one cook each. These parties to take the field June 1 and continue work, if the season permit, until November 1.

ESTIMATE OF EXPENSES.

For two topographic parties: two chiefs and two permanent assistants; work to commence June 1, 1889, and continue five months in the season of 1889, and one month in the season of 1890; area 3,000 square miles....	$14,000

NEVADA AND CALIFORNIA.

It is proposed to organize the topographic work in these States under one division.

That the area to be surveyed in California comprise such portions of the drainage basins of the Yuba, American, Cosumne, Mokelumne, Stanislaus, Truckee and Carson Rivers, as are now unmapped and included in atlas-sheets, long. 120° 00′ lat. 38° 30′, long. 120° 00′ lat. 39° 00′, and long. 121° 00′ lat 38° 00′, in all about 3,000 square miles.

That the area to be surveyed in Nevada comprise such portions of the drainage basins of the Truckee and Carson Rivers as are included on atlas-sheets, long. 119° 00′ lat. 38° 30′, long. 119° 30′ lat. 38° 00′, long. 119° 30′ lat. 38° 30′, and long. 119° 30′ lat. 39° 00′, in all about 4,000 square miles.

The area in both States to be surveyed with sufficient detail to construct a map on the scale of 1 inch to 2 miles, and in contours having intervals in the valleys of 20 feet, in the rougher portions of the country 50 feet, and in the higher mountains 100 feet.

That the organization to perform the work in both States consist of one triangulation and supervision, and four topographic parties, with such other smaller organizations as may from time to time be necessary, the whole to be under the immediate supervision of Mr. E. M. Douglas, with Messrs. A. F. Dunnington, R. H. McKee, G. T. Verrill, and R. H. Chapman as assistants in charge of parties. The triangulation party, besides Mr. Douglas as chief, to consist of one assistant, two packers, and one cook. Each topographic party, besides its chief, to consist of two or three field assistants, as the exigencies of the work demand, two packers or teamsters, and one cook These parties to take the field in May and continue work till the last of October.

ESTIMATE OF EXPENSES.

For one triangulation and four topographic parties: five chiefs of parties and six permanent assistants; work to commence May 15, 1889, and continue five months in the season of 1889, and one month in the season of 1890; 7,000 square miles	$35,500
Supervision, including salary of chief topographer in charge and his traveling expenses	6,000
Disbursements, including salary of disbursing agent and his traveling expenses	2,500
Instruments	3,000

RECAPITULATION.

California and Nevada	$35,500	Supervision	$6,000
Colorado	37,000	Disbursements	2,500
Idaho	14,000	Instruments	3,000
Montana	7,000		
New Mexico	15,000	Total	$120,000

HYDRAULIC WORK.

The operations of the hydraulic survey and of the engineering survey up to the present time have been under the charge of Capt. C. E. Dutton, of the Ordnance Corps, now on duty with the Geological Survey. It is proposed to continue this arrangement for the present and until a chief hydrographer is appointed, when the work will be divided.

In Montana no hydraulic work has been projected for the present season. Mr. R. S. Tarr is now at Helena, but he has been sent there to gather information required for the Senate committee, for which duty he has proved himself to be very apt, and it will for the next two months probably occupy all his time.

In Wyoming the territorial engineer, Mr. Mead, is starting the gauging of several streams and has been promised whatever cooperation can be afforded him.

In the South Platte the State of Colorado has appropriated money for the guaging, and the new State engineer prefers to conduct it himself without cooperation or overlapping by this Survey.

In the Arkansas Valley Mr. Robertson has been stationed, with Mr. Irving as an assistant, and he is instructed to establish a permanent station at Canyon City, another at Buena Vista, and a third near Huerfano, and minor stations at other points.

In the Rio Grande Mr. George T. Quinby has been ordered to establish one first-class station in the San Luis Valley and to maintain the one at Embudo; also to keep a station on the Jemez and on the Chama, and also to keep records of the flow of the more important tributaries of the Rio Grande. These have been well reconnoitered during the past winter and spring by the assistants at Embudo. Mr. Williams is now at El Paso establishing a gauging station.

Mr. Farish has been instructed to establish gauging stations on the Gila, Salt, and Verde Rivers, and to measure the flow of smaller streams in the Gila drainage.

Mr. Trowbridge has been sent to California to acquaint himself with the progress made by the State survey in gauging the rivers from the Yuba to the Stanislaus and to take such further action in the same direction as may be necessary.

Mr. Harrison has been sent to the Lahontan basin to establish stations on the Truckee River and its tributaries and on the Carson River.

Mr. Hopson has been sent to Boisé City to prepare for the gauging of the Snake River and its tributaries. This will be heavy work, and as soon as practicable another man will be sent there, either Mr. Williams or Mr. Newell.

In addition to gauging work, it is proposed to establish at selected convenient stations evaporation pans. The selection of places has in some cases been determined, in others not, but all will be determined soon. In conjunction with evaporation measurements it will be necessary to use the thermometer, the psychrometer, and the rain-gauge. Such stations it is proposed to make first-class stations. Their equipment will be:

(1) Inclined scale for registering the rise and fall of the stream.
(2) Evaporating pan.
(3) Thermometer and whirled psychrometer.
(4) Rain-gauge.

The gauging of streams with the current meter will be performed by a migratory party moving from station to station. It will be necessary to keep a permanent employé at such stations.

Second-class stations will also be established at points at which only a part of the above observations will be made. The observers of the second class will probably have to be paid a small compensation, which it is hoped will not exceed $10 per month. The probable number will not be large.

Third-class stations will be selected largely at high altitudes, though not exclusively so, at which only rain-gauges will be kept. Skilled meteorologists, with much practical experience, state that observations with the psychrometer must be made by well-trained observers in order to be of any value, and they all discourage the idea of placing such instruments in the hands of the untrained. In a few cases it will be practicable to find intelligent volunteers who may be intrusted with them, but in most cases not.

Mr. Newell has spent some time and attention in examining the question of measuring transported sediments. The problem is a difficult one. A beginning has been made, however, and it is proposed that he shall continue his researches. At present it seems necessary to experiment for a time in order to ascertain by what processes and apparatus the problem shall be attacked.

Mr. Curtis will be recalled to Washington immediately to organize a branch of this office for systematizing observations, preparing blank forms and reports, and proper forms of records of all results of observations made in stream-gauging, evaporation and meteorology.

ESTIMATE OF EXPENSES.

Salary of F. H. Newell	$1,500
Salary of G. E. Curtis	1,400
Salary of J. B. Williams	1,200

Salary of eight assistants, at $900	$7,200
Salary of four assistants, at $720	2,880
Total	14,180
Purchase of instruments	4,000
General field and traveling expenses	8,000
Hired men	3,020
Paid observers	3,000
Total hydrographic work	32,200

ENGINEERING SURVEY.

It is recommended that this work be continued under the charge of Capt. C. E. Dutton, and that work be prosecuted as follows:

UPPER MISSOURI DIVISION.

It is proposed to place this work under the charge of Mr. H. M. Wilson.

The work in this division being in the least advanced state of development, and its general features being imperfectly known, the first season should be devoted mainly to a preliminary reconnaissance. It is proposed to examine the general irrigation problem in—

(*a*) The Forks of the Missouri; i. e., the Gallatin, Madison and Jefferson Valleys.

(*b*) The Yellowstone Valley from the Park to Miles City, or perhaps Glendive.

(*c*) The Missouri from the junction of the Forks to Fort Benton.

(*d*) The Milk River country.

ESTIMATE OF EXPENSES.

Salary of engineer	$2,400
Field assistants	1,500
Hired men	1,500
Field supplies, instruments, animals, forage, incidentals	2,600
Total	8,000

COLORADO DIVISION.

It is proposed to place this work under the charge of Mr. Edwin S. Nettleton.

It is proposed to make a study of the Arkansas valley from its head waters to the one hundredth meridian, with a view of projecting the best method of irrigation upon the most comprehensive plan; also to select the most important or principal reservoir sites; to plan the construction of several important reservoirs and estimate costs.

The study of the Arkansas system includes also the study of the Huerfano as its most important tributary, in which system reservoirs

will be conspicuous. There are several fine sites for very large reservoirs in the Huerfano drainage, with an abundance of water to fill them.

ESTIMATE OF EXPENSES.

Salary of supervising engineer, in charge also of the division	$4,000
Field assistants	4,500
Hired men	4,000
Field supplies, instruments, animals, forage, and incidental expenses	7,000
Total	19,500

NEW MEXICO DIVISION.

It is proposed to place this work under the charge of Mr. Alexander O. Brodie.

The valley of the Rio Grande presents several natural subdivisions :

(*a*) The San Luis Valley.

(*b*) The Española Valley, including the valley of the Chama and its tributaries.

(*c*) The Jemez Valley.

(*d*) The Middle Rio Grande, extending from Bernalillo to San Marcial and including the East Puerco drainage.

(*e*) The Jornada del Muerto and Mesilla Valley ; the Taos Valley would also make an interesting study on a smaller scale.

It is proposed in the coming season to make a special study of the project for a dam at El Paso, with settling reservoirs in the trough of the Rio Grande through the Jornada del Muerto, and a project for a canal starting fro :: Fort Selden to irrigate the Mesilla Valley, and another starting at El Paso to irrigate the valley below that town. It is also proposed to study the Jemez subdivision in full detail, and, if practicable, the East Puerco, which is one of the most promising fields.

ESTIMATE OF EXPENSES.

Salary of engineer	$3,000
Field assistants	2,000
Hired men	1,800
Field supplies, instruments, animals, forage, incidentals	3,200
Total	10,000

IDAHO DIVISION.

It is proposed to place this work under the charge of Mr. A. D. Foote.

The projected work is the study of the capabilities of this valley above the Payette and the development of plans for utilizing a vast area amounting to nearly 4,000,000 acres, or over 6,000 square miles. This field is so extensive that probably most of the work the present year will be of a reconnaissance character, though the Boisé River drainage is now well known and the Payette to some extent.

In general the plans of work and their details will be more fully matured after an opportunity to confer with the division and supervising engineers is presented.

ESTIMATE OF EXPENSES.

Salary of engineer	$3,000
Field assistants	2,000
Hired men	2,000
Field supplies, instruments, animals, forage, and incidentals	4,000
Total	11,000

LAHONTAN DIVISION.

This division embraces Nevada and that portion of California that drains eastward into Nevada.

It is proposed to place this work under the charge of Mr. Lyman Bridges.

For this division the work projected includes the development of a plan for utilizing the waters of the Truckee and Carson basins by canals and reservoirs; also a reconnaissance of the Humboldt, Walker River, and Honey Lake basins.

ESTIMATE OF EXPENSES.

Salary of engineer	$3,000
Field assistants	3,000
Hired men	3,000
Field supplies, instruments, animals, forage, and incidentals	6,500
Total	15,500

CALIFORNIA DIVISION.

In the drainage basins of the Sierra Nevada north of the Cosumne or Mokelumne there is but little demand for irrigation, and whatever demand exists is more than met by the old mining ditches and reservoirs, whose waters are no longer permitted to be used in washing gravels. In the valleys immediately south of the Mokelumne there is some demand for water, and this demand steadily increases southward until it becomes very great in the valley of the Kern. On the western sides of the Sacramento and San Joaquin Valleys, i. e., upon the eastern slopes of the Coast Ranges, the scarcity of water is extreme, while the extent of arable land is very great. It is believed that important areas of this land may be irrigated by the development of a system of reservoirs. Many situations for reservoir sites are known to exist in these ranges, and the rain-fall on the mountains is probably sufficient to fill many of them. Some map work has also been accomplished on a suitable scale, and it is therefore proposed to begin work upon the eastern slope of the Coast Range. Maps are already in process of construction for some of the drainage basins of

the western slope of the Sierra Nevada, where the demand for increased areas of irrigation is great. As this work proceeds the Stanislaus and more southern rivers will engage the attention of the engineering corps. One of the most important problems in irrigation to be solved in California relates to the use of the Colorado River in the southeastern part of the State. Already much is known in the Survey in relation to this subject, but for climatic reasons the work can best be prosecuted during the winter months. It is therefore proposed to enter upon this investigation later in the year, and to place it in the hands of Mr. William Hammond Hall.

ESTIMATE OF EXPENSES.

Salary of supervising engineer, also in charge of division	$4,000
Field assistants	2,500
Hired men	2,000
Field supplies, instruments, animals, forage and incidentals	3,500
Total	12,000

RECAPITULATION.

Montana Division	$8,000
Colorado Division	19,500
New Mexico Division	10,000
Idaho Division	11,000
Lahontan Division	15,500
California Division	12,000
Total	76,000

Total appropriation		$250,000
For topographic work	$120,000	
For hydraulic work	32,200	
For engineering work	76,000	
		228,200
To be used for contingent purposes		21,800

The above report is submitted to the Secretary for his examination and consideration, and his approval of the same is requested.

I am, with great respect, your obedient servant,

J. W. POWELL,
Director.

INSTRUCTIONS.

In pursuance of the above plan, the following instructions were issued:

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., May 25, 1889.

Prof. A. H. THOMPSON,
Chief Topographer, Irrigation Survey:

SIR: You are hereby continued in charge of the topographic work of the Irrigation Survey. The sum of $120,000, from the appropriation for an irrigation survey for the fiscal year 1890, is allotted to your work. From this are to be paid the salaries of all assistants assigned you, and all field expenses of every kind.

You are also authorized to employ such laborers as may be necessary to the proper conduct of your work, having due regard for economy. You will employ such persons by the month or day, as circumstances require, but will not pay a greater monthly salary than $60 without special permission from this office.

You are also authorized to make such purchases of field supplies and material, either in person or by your assistants, as may be necessary for your work.

You will make a monthly report of progress, which should be submitted at the earliest possible date after the close of each month.

The following instructions have been prepared for your guidance in the prosecution of the survey under your charge:

MAPS.

All field work for the general map should be done on a scale of 1 inch to 1 mile, and in contours having a vertical interval of 100 feet in high mountain country, 50 feet in the lower and less rough country, and 20 feet in all areas of possible irrigable lands or sites of possible reservoirs.

A larger scale and less contour interval may be used for special maps.

HORIZONTAL CONTROL.

Horizontal control should be secured by primary triangulation, secondary triangulation, plane-table intersections and sketches, and plane-table traverses between located points.

Primary triangulation should be done with accurate instruments, and at least two stations should be located on each atlas-sheet. Secondary triangulation may be done with less refinement, but must be accurate within the limits of the scale, and locate a sufficient number

of stations on each plane-table sheet for topographic work. Plane-table stations must be made on secondary triangulation and other convenient points so chosen that the whole country can be seen, and intersections made to locate all principal topographic features. In favorable country the secondary triangulation may often be done over limited areas by the plane-table. All contouring and location of topographic features between the intersected points must be done from plane-table stations. Primary and secondary triangulation should precede plane-table work.

All roads and important topographic features must be traversed and sketched by plane-table methods—courses being determined by the magnetic needle, and distances measured by instrumentation. All streams must be traversed, and special attention paid to accurate connection of their courses with the secondary triangulation and the topographic features of their immediate valleys. The outlines of all valleys in the mountains and foot-hills, as well as the plains, broader valleys, terraces and benches of the lower country, must be accurately located by plane-table intersections or traverses.

Instruments.—Theodolites of approved construction should be used in the primary triangulation; gradienters and plane-tables in secondary triangulation; traverse plane-tables for traverse work; odometers, chains and stadia rods for the distances in traverses, and compasses for courses.

VERTICAL CONTROL.

One or more points on each atlas-sheet must be accurately determined in altitude and used as primary reference or bench-marks for that sheet. All secondary triangulation and other plane-table stations, as well as other convenient points, must be connected with the primary bench-mark by leveling, either angular or spirit. This work should precede the contouring of plane-table sheets or traversing.

All plane-table intersections must be located in altitude by angulation. All traverses must be located in altitude by angulation, spirit-level or barometer, as the special case requires. In the use of either method frequent reference must be had to the primary and secondary bench-marks.

The slope of all possible irrigable lands must be determined by level lines frequently crossing them. The gradients of all streams must be determined with great care as high as any possible reservoir sites, and the grade-curves of their immediate valleys and of reservoir sites located frequently by instrumentation. Contours indicating the outlines of valleys, plains, terraces and benches must be accurately located by frequent instrumental determinations.

Instruments.—The Y spirit-level should be often used in determining the gradients of streams, reservoir sites, etc. Gradienters

and telescopic alidades may be used in angular leveling; aneroid and mercurial barometers in traversing.

Herewith you will find the general plan of work as approved by the honorable the Secretary of the Interior.

Yours, with respect,

J. W. POWELL,
Director.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., May 25, 1889.

Capt. C. E. DUTTON,
Chief Engineer, Irrigation Survey:

SIR: I desire herewith to place before you certain governing considerations of a general character with reference to the surveys you are expected to make and the results you are expected to accomplish through the employment of the engineering corps.

In each hydrographic basin it is desired to attack these problems: What are the available sources of water supply? and by what means may the water be most fully utilized? A hydrographic basin may mean the water-shed of a large stream or of a small one—of a great river or of one of its tributaries. But whether it means a trunk stream or a branch of it—a question to be decided by the engineer—it is assumed that there is some form of development and construction of works which may be adjudged to be the best that the engineer can devise. The engineers should take no account of works which are already constructed; nor should their judgment be swayed by any opinion on their part as to what works private enterprise and capital are likely to undertake in the next few years. They should rather address themselves to the question already propounded: What is the best system; the one which will utilize the greatest amount of water and produce the greatest amount of irrigation? It is not forgotten that as a practical matter irrigation development in each district starts with a small beginning, and with works proportional to that beginning, involving great waste of water and great cost for maintenance; that it advances through successive stages by more costly works superseding the primitive ones. But of these the engineer should take no account. His project should embrace what is in his judgment the best system, irrespective of what is or actually may be constructed. At the same time his project should be a practical one, involving no extravagance of engineering, not transcending the possibilities of attainment and maintenance after attainment.

The plan should have also a certain unity, and should contemplate a single system of works for each irrigation district. If both reservoirs and canals are required the reservoirs should, if possible, be

projected as adjuncts of the canals. No doubt it will happen sometimes that the rivers alone are more than sufficient for the available land, as in some valleys of the northernmost States and Territories; or that reservoirs alone are possible, as in parts of the southernmost Territories. Still, even in such cases unity of plan should be kept in view so far as practicable.

Engineers should seek to devise plans to serve the greatest amount of irrigation with the least expense. When the land is in excess of the water the plans should be made to utilize all available water. When the water is in excess of the land the plans should be made to utilize all the available land.

Engineers should seek to minimize the distributive works by which water is taken from canals and reservoirs and put upon the land. With a given high-line canal it will generally be possible to propose many ways of distributing its water. But the distributive system will in other cases probably be of a distinctive character, forming a vital part of the entire project, and its employment in the project will then be necessary.

In carrying out the actual survey work in the field it will not be necessary, it is believed, to actually run the canal lines by transit and level with cumbrous and expensive parties of rodmen, chainmen, axmen, cooks and teamsters and mark the lines by stakes on the ground. For the lawful purposes of the survey a simpler, far less expensive, and more generally useful method is contemplated. It is to be borne in mind that this survey is not primarily designed for the benefit of private parties who may contemplate the construction of works, though if they should incidentally derive benefit therefrom it would be a matter for congratulation. Its first object, as expressed in the statute directing that the survey be made, is for the information of the Congress and of the State and Territorial legislatures and the guidance of future legislation with respect to the arid lands and the use of the natural waters. The second object of the survey is to select sites for reservoirs and other hydraulic works necessary for irrigation, and to reserve the same for public purposes, that they may not fall into the possession of individuals or corporations. The third purpose is to select and reserve the irrigable lands until the Congress shall decide upon the best method for their disposition to actual settlers. There is a fourth object, of equal importance to the others, namely, to guide the agriculturists of each great hydrographic basin to the most economic method of utilizing the waters for irrigation in such a manner that the greatest area may be cultivated thereby. Hence it is designed to spread upon good maps and set forth in printed reports and records the facts as they exist, and the possibilities which may be hoped for in their entirety. This should be done with sufficient but not excessive detail. It should comprise not merely delineations of the routes of canals and the locations of reservoirs,

but all the essential accessory facts inherent in the country itself. The basis of work, then, is, in the view of the Director, a topographic map.

Such maps have already been begun by the topographic survey in those districts where work is contemplated in the present year, and upon some of them large progress has been made For the general topographic maps the field-work is all done on a scale of 1 inch to the mile and in contours having a vertical interval of 100 feet in high mountain country, 50 feet in the lower and less rough country, and 20 feet in all areas of possible irrigable lands or sites of possible reservoirs. Larger scale maps with less contour intervals are contemplated for special maps. In the construction of these maps the horizontal control is secured by primary and secondary triangulation, by plane-table intersections, and by plane-table tracing between located points. Points in abundance are located on each plane-table sheet, and they will be located with an accuracy which is well within the limits of the scale on which the map is projected. On each atlas-sheet one or more points has its altitude accurately determined and is used as a primary reference or bench-mark for that sheet, and all secondary triangulation and plane-table stations, as well as other points, are connected with these bench-marks by actual leveling. The slopes of all possible irrigable lands are determined by lines of level frequently crossing them. The gradients of streams are determined with great care by leveling as high as all possible reservoir sites, and the grade curves of their immediate valleys and of reservoir sites are frequently located by instrumentation.

When these maps are placed in the hands of the engineer, it is believed that he can locate upon them by a simple reconnaissance the line of a canal, without the necessity for a large field party and its expensive equipment, and that the result will answer the practical purposes contemplated in the law. It may happen, however, that actual leveling will have to be done sometimes, and whenever it is necessary it is expected, though the effort should be to avoid as much of such work as practicable. Information as to the location of all determinate points on the map can always be obtained from the note-books of the topographic parties.

Few of the maps are yet engraved; but photographs of the original drawings and of the plane-table sheets, as rapidly as the latter are finished, can be made in this office and placed in the hands of the engineers.

The exigencies of the service demand that the work of the engineers shall be commenced at an early date, in order that complete systems of irrigation can be projected and the plans reported to Congress at its next session. The engineers engaged in planning works will realize that could they be supplied with maps already constructed and with the results of a hydraulic survey, giving them

the facts relating to the volume, evaporation, sedimentation, etc., of the several streams they are investigating, it would be highly advantageous to their work; and in the prosecution of plans hereafter it is hoped that such data can be furnished the engineers when they take the field; but it is impossible to do this for the present season, and it therefore becomes necessary for them to adjust themselves somewhat to the imperfect conditions and to consult the field sketches and notes of the topographer, and to obtain from the hydrographers preliminary and incomplete statements of the facts collected by them. It is hoped that they will adapt themselves to the circumstances by the wisest methods, and work with such fragmental and incomplete data as may be on hand, leaving it to a later day to complete all the topographic and hydraulic data necessary for final reports. Each project of a canal will have some special features which can not properly be expressed upon the general topographic sheets, such as headworks, dams, water-falls, and special distributive works which may form an integral part of the system. In so far as these call for topographic representation upon a much larger scale, special maps can be estimated for and requisition made for them upon this office. In so far as they call for representation in engineering plats and conventions, the engineers will be expected to make the necessary surveys and delineations.

Reservoirs which constitute an essential part of any unified project, will in most cases demand special plats for their representation, and more or less survey by the engineer to cross-section their basins, properly estimate their capacities, and define the characters and proportions of the dams. It should be remembered that the ends in view are not actual constructions by the Government, but plans and estimates for the use of the people, and reports should be prepared in the simplest manner possible.

The selection of reservoir sites involves their withdrawal from occupation and entry by settlers under the various land acts. This should be one of the first subjects to engage the engineer's attention. He should first reconnoiter such localities as seem to offer facilities for good reservoir sites, and form a preliminary judgment of their possible areas of water surface without entering into detailed surveys. To this surface should be added for each site an ample margin of safety around it. He should identify its situation upon the Land Office plats in the local land office having jurisdiction over it, and make report to this office that a practicable site has been selected, specifying the ranges, townships, and sections. No subdivision smaller than a section should be taken, and if the boundary of the reservation cuts through any section, the whole section should be embraced in the reservation. So far as this specification is concerned, it is immaterial if a part of the land has already been filed upon or patented.

In case the site is upon land which is unsurveyed by the Land Office, a monument should be erected at a point having a height such that a line of level running around the basin and through the base of the monument will embrace all the land which it is desired to withdraw. It will be sufficient for the purpose of a preliminary withdrawal to describe the position of such monument in terms which will enable its situation to be subsequently identified, to specify the township or townships within which the site is located, when it can be done, and to declare that all land within such basin lying below a level-line through the base of the described monument is withdrawn as a reservoir site.

The preliminary withdrawal of reservoir sites is an operation which should be conducted with secrecy and dispatch, and every effort made to avoid being anticipated by jumpers and speculators.

For properly "investigating the extent to which the arid region can be redeemed by irrigation," it is necessary for the engineer to know as much as possible of the available water supply, how much of it he can secure in his canals and reservoirs, and how much he is likely to lose by evaporation and by other causes which he can not control. It is therefore necessary to determine the amount of water flowing in the streams, the variation of flow throughout the year, the rain-fall, and the evaporation. For these investigations a corps of hydrographers has been organized during the past winter, and they have been experimenting and practicing with a view to ascertaining the best instruments and methods of work.

In this branch of the work the gauging of streams is for the present the most urgent. The hydrographers will be stationed in the several divisions to organize and prosecute the work of stream-gauging under the eye of the engineer, who will select those streams which demand the first gauging, and which are the subjects of their immediate wants. Evaporation measurements will also be undertaken with special reference to determining the amount of evaporation from water surfaces.

Monthly reports will be required setting forth the operations of the engineer in full.

Yours, with respect,

J. W. POWELL,
Director.

[General instructions for hydrographers.]

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., May 25, 1889.

Capt. C. E. DUTTON,
Chief Engineer of the Irrigation Survey:

SIR: The duties which devolve upon the hydrographers will be at once of a highly scientific and practical character, and will consist in ascertaining by systematic observations and measurements the values of numerous factors or qualities which must be known in order to fully carry out the purpose of the law which requires an investigation of the extent to which the arid lands can be redeemed by irrigation. They may be mentioned in the following order:

(1) Measurements of water supply.
(2) Measurements of the loss of water by evaporation.
(3) The investigation of the climatology of the arid region with reference to agriculture by irrigation.
(4) Measurements of sediments transported by streams
(5) The duty of water.
(6) Collection of general information.

(1) The measurement of water supply will consist primarily in the gauging of streams. To this end the methods developed at Embudo will be followed for the present, but with time and experience it is hoped that improvement will come. For this purpose stations will be established on streams to be gauged at points selected and a systematic record will be kept of the rise and fall of the streams by means of inclined graduated rods, and the stations will be visited by the hydrographers so as to gauge repeatedly at different stages of the water until a sufficient number of stages have been gauged to admit of a formula for the stream and the station. The stream beds will be plotted and the slopes ascertained by leveling. Full records will be kept by the hydrographers of all their gauging work and the results reported monthly to this office.

(2) The evaporation will also be measured by the general methods employed at Embudo. The quantity to be ascertained is the evaporation from water surfaces. Wherever practicable it is desirable to combine station work by placing evaporometers at the same stations as river gauges; but this must be influenced by considerations of economy and the intelligence of the observers.

(3) The study of the climatology of the West will be mainly the work of the central office, as the data upon which it depends are of regional extent, and most of them are collated by the Signal Service, whose records are accessible only in Washington. But hydrographers are expected to furnish some accessory data, and to cultivate in their divisions the interest of volunteer observers and to promote the

organization of meteorological societies. They are cautioned, however, not to duplicate the work of the Signal Service, but to maintain a most cordial and cooperative attitude towards the observers of that Bureau and to conform to its methods.

Rain gauges will be placed at stations not occupied by Signal Service observers, and for the present localities at higher altitudes especially need investigating as to the amount of precipitations, and as a general though not invariable rule preference should be given to higher altitudes in choosing rain-gauge stations. It is deemed unadvisable to use the sling psychrometer, except in cases where the observer is known to be a man of exceptional intelligence and skilled in the use of meteorological instruments.

(4) The measurements of sediments transported is a subject which must await future development, and no instructions can be given for the present with reference to it.

(5) Care should be taken, whenever opportunity occurs, to ascertain the duty of water in all localities where irrigation is practiced. The subject should be investigated personally, and too much reliance should not be placed on the mere statements of farmers unsupported by careful measurement. As the duty will vary, much inquiry is necessary to ascertain upon what causes such variations depend. The following factors seem to be of prime importance: (1) Method of flooding lands; (2) climate; (3) character of soil and subsoil; (4) kind of crop raised.

(6) The central office will be frequently called upon to furnish information not only to Congress, but to thousands of individuals throughout the country upon the subject of irrigation. In short, it must constitute itself a bureau of information. The hydrographers are expected to have their eyes open to all facts relating to irrigation, and to keep the central office advised of everything of interest.

Reports must be made monthly, embracing a full account of all operations during the month. Records of guagings, with the plates of the section at the station, and records of soundings and leveling must be kept by the hydrographers and copies of them furnished to this office at such times as will hereafter be stated and upon such forms as shall be prescribed. They will also collate the reports of the rain-gauge and other observers and consolidate them, forwarding the consolidated report to this office.

Yours, with respect,

J. W. POWELL,
Director.

With the above general instructions, common to all operating in like branches of the work, the parties were sent to the field with specific orders to carry on the survey in designated areas. A detailed account of the progress of the survey for the

fiscal year ending June 30, 1889, is contained in the reports of Professor Thompson and Captain Dutton appended hereunto.

AREAS SURVEYED.

The following statement exhibits in tabular form the areas covered by the topographic survey in the several States and Territories wherein it was prosecuted, the reservoir sites and canal sites that have been surveyed in each State and Territory, the additional reservoir sites selected for segregation, and the total selection of irrigable lands for segregation. The table does not include a great number of reservoir sites and canal sites that have been discovered and from which selections are to be made hereafter:

Areas mapped by the Topographic Branch, Irrigation Survey.

States.	1888.	1889.	Total.
	Sq. miles.	*Sq. miles.*	*Sq. miles.*
California	1,580	3,268	4,848
Colorado	13,000	10,200	23,200
Idaho	.....	1,900	1,900
Montana	3,600	1,670	5,270
New Mexico	3,800	2,570	6,370
Nevada	250	1,642	1,892
Total	22,230	21,250	43,480

Expenditures from October 3, 1888, to June 30, 1889	$172,171.83
Cost per square mile	3.95

Reservoir sites surveyed in Arkansas River division, Colorado.

	Name.	Location.	Height of dam.	Area.	Capacity.
			Feet.	*Acres.*	*Acre-feet.*
1	Twin Lakes	Lake County	60	1,297	130,000
2	Cottonwood	Chaffee County	70	166	8,400
3	Leadville	Lake County	100	280	8,875
4	Monument	El Paso County	40	47	5,630
5	Pring	....do	60	198	4,500
6	Hayden	Lake County	100	1,113	45,000
7	Clear Creek No. 1	Chaffee County	60	350	7,000
8	Clear Creek No. 2	....do	45	64	1,800
9	Tennessee	Lake County	70	1,889	37,000
10	Sugar Loaf	....do	60	1,070	45,000

Canal lines surveyed, Arkansas division.

	Name.	Location.	Height of dam.	Area.	Capacity.
1	Coolidge Canal Line*	.....	.....	.....	.....

* Leaves the Arkansas River on the north bank 12 miles west of the line between Kansas and Colorado, and extends eastward to a point 30 miles east of said lines, and then turns northward in a very direct line to the town of Leoti, Kans., 30 miles north of the most southern part of its line.

Reservoir sites surveyed in Stanislaus and Tuolumne Basins, California.

	Name.	Location.	Height of dam.	Area.	Capacity.
1	Bear Valley Reservation	T. 7 N., R. 18 E	30		1,500
			40		3,447
			50	356	6,917
2	Highland Lake*	Sec. 6, T. 7 N., R. 20 E.			
3	Kennedy's Meadow	T. 5 N., R. 20 E	50	86	1,369
			70	114	3,402
			90	140	5,943
4	Kennedy's Lake	T. 5 N., R. 21 E	20	86	1,041
			30	109	2,018
5	Tuolumne Meadows	Tuolumne County, T. 1 S., R. 23 and 24 E., M. D. M.	50	870	23,753
			60	972	32,968
			80	1,174	54,408
6	Lake Eleanor	Tuolumne County, T. 2 N., R. 19 E	50	678	8,000
			70	1,012	25,776
			90	1,134	47,290
			100	1,193	58,927
7	Lake Tenaiya	T. 1 S., R. 23 E., M. D. M	25	470	6,717
			35	530	11,719
			55	603	23,083
8	Little Yosemite Valley	Mariposa County, T. 2 S., R. 22 and 23 E.	110	640	14,928
			130	765	29,116
			160	860	53,700

* Surveyed, but full details not received at civil engineer's office.

Reservoir sites surveyed in Carson and Truckee Basins in California and Nevada.

	Name.	Location.	Height of dam.	Area.	Capacity.
1	Donner Lake	Nevada County, Cal	25	1,337	22,200
2	Independence Lake	do	40	984	23,700
3	Webber Lake	Sierra County, Cal	30	778	11,200
4	Hope Valley	Alpine County, Cal	70	219	2,440
			110	1,337	30,300
			130	1,595	61,000
			150	1,803	95,000
5	Long Valley	Douglas County, Nev	90	1,086	34,400

Reservoir sites surveyed in Sun River Basin, Montana.

	Name.	Location.	Height of dam.	Area.	Capacity.
1	Sun River Reservation No. 1	Lewis and Clarke and Choteau Counties	58	300	6,000
2	Sun River Reservation No. 2	do	100	350	13,000
3	Sun River Reservation No. 3	do	96	1,000	35,000
4	Sun River Reservation No. 4	Lewis and Clarke County	94	700	20,000
5	Sun River Reservation No. 5	do	84	1,500	45,000
6	Sun River Reservation No. 6	do	66	300	6,000
7	Sun River Reservation No. 7	do	39	250	6,000
8	Sun River Reservation No. 8	do	23	130	2,000
9	Sun River Reservation No. 9	do	36	70	1,000
10	Benton Lake	Cascade County		7,000	

Canal lines surveyed in Sun River Basin, Montana.

	Name.	Location.	Height of dam.	Area.	Capacity.
1	Canal No. 1*	Choteau and Cascade Counties			
2	Canal No. 2†	Lewis and Clarke County			
3	Canal No. 3‡	------do			

*Taken out on the north side of Sun River in sec. 21, T. 22 N., R. 7 W., 1 mile below Reservation No. 1. Runs in a southeasterly direction through T. 22 N., R. 7 W., and T. 21 N., R. 6 W.; thence easterly through the southern portion of T 21 N., R. 5 W.; thence northeasterly through T. 21 N., R. 4 W, Enters T. 21 N., R. 3 W., at SW. corner section 6 and then turns easterly running through the north tier of sections in T. 21 N., ranges 3 and 2 W.; thence northeasterly through T. 22 N., R. 1 W., to crossing of Big Muddy Creek. Total length, 70 miles.

†Taken from the top of reservoir No. 2 and runs in a southeasterly direction 2½ miles; thence northerly 2½ miles; thence easterly 3 miles to reservoir No. 9; thence southerly to reservoir No. 8, where it is turned into a natural water-way, supplying reservoirs No. 7 and 5. Total length of line, 14 miles.

‡Taken from bottom of reservoir No. 5 in sec. 30, T. 21 N., R. 6 W., and running southeasterly through sections 30, 29, 28, 33, 34, and 35, T. 21 N., R. 6 W.; thence southwesterly through sections 2, 3, 4, 5, 8, and 9, T. 20 N., R. 6 W., ending one-half mile below the town of Augusta. Total length, 10 miles.

Survey of reservoir in Rio Grande Valley, near El Paso.

	Name.	Location.	Height of dam.	Area.	Capacity.
1	Lake Constance	Mesilla Valley	60	24,900	537,000

Reservoir sites selected for segregation.

MONTANA.

No.	Name.	County.	Basin.	Capacity.	Area segregated.	Remarks.
				Acre feet.	*Sq. miles.*	
1		Meagher			2	
2		Jefferson			1	
3		do			2	
4		Lewis and Clarke			2	
5		do			2	
6		Choteau			2	
7		do			36	
8		do			36	
9		do			1	
10	Sun River Reservoir, No. 1	Choteau and Lewis and Clarke.	North Fork of Sun River		92	Reservation including Sun River Reservoirs, Nos. 1, 2, 5, 7, 8, 9.
11	Sun River Reservoir, No. 2	do	do			
12	Sun River Reservoir, No. 3	do	do			
13	Sun River Reservoir, No. 4	Lewis and Clarke	do		60	Sun River Reservoirs, Nos. 3 and 4.
14	Sun River Reservoir, No. 5	do	do			
15	Sun River Reservoir, No. 6	do	do		12	Sun River Reservoir, No. 6.
16	Sun River Reservoir, No. 7	do	do			
17	Sun River Reservoir, No. 8	do	do			
18	Sun River Reservoir, No. 9	do	do			
19 to 61	Yellowstone Reservoir system		Yellowstone River		396	Partly irrigable lands.
	Smith Creek Reservoir system		Smith Creek		288	
	Elk Creek Reservoir system		Elk Creek		52	
	Musselshell Reservoir system		Musselshell		324	
	Lake Mason Reservoir system				36	
	Judith River Reservoir system		Judith River		52	
	Wolf Creek Reservoir system		Wolf Creek		12	
	Belt Mountain Reservoir system		Missouri River		93	
	Box Elders Reservoir system		Box Elder Creek		9	
	Shonkin Creek Reservoir system		Shonkin Creek		164	
	Little Blackfoot Reservoir system		Teton River		90	
	Total				1,762	

CALIFORNIA.

1	Clear Lake	Lake	Clear Creek			
2	Independence Lake	Nevada	Little Truckee River		10¼	
3	Webber Lake	Sierra	do		9	
4	Donner Lake	Nevada	Truckee River		15	

Reservoir sites selected for segregation—Continued.

CALIFORNIA—Continued.

No.	Name.	County.	Basin.	Capacity.	Area segregated.	Remarks.
				Acre feet.	*Sq. miles.*	
5	Monache Meadows Reservoir	Tulare	South Fork, Kern River		56	
6	Big Meadows Reservoir	do	Trout Creek, Kern River		10	
7	Little Yosemite Reservoir	Mariposa	Merced River		5	
8	Tenaiya Lake	Tuolumne	do		11	
9	Tuolumne Meadows Reservoir	do	Tuolumne River		10	
10	Eleanor Lake Reservoir	do	Middle Fork, Tuolumne		22	
11	Kennedy's Meadow Reservoir	do	Middle Fork, Stanislaus		6	
12	Kennedy's Lake Reservoir	do	do		4	
13	Bear Valley Reservoir	Alpine	North Fork, Stanislaus		6	
14	South Highland Lake Reservoir	do	Stanislaus River		?	
15	Rattlesnake Creek Reservoir, No. 1	Modoc	Pitt River		61	
16	Rattlesnake Creek Reservoir, No. 2	do	do		20	
	Total				*252	

COLORADO.

1	Twin Lakes	Lake	Lake Creek, Arkansas River		14	
2	Leadville Reservoir	do	East Fork, Arkansas River		11½	
3	Clear Creek Reservoir, No. 1	Chaffee	Clear Creek, Arkansas River		6	
4	Hayden Reservoir	Lake	Arkansas River		13	
5	Sugar Loaf Reservoir	do	Lake Fork, Arkansas River			
6	Crane's Reservoir	do	Tennessee Fork, Arkansas River			
7	Tennessee Reservoir	do	do		52	Reservation including Nos. 5, 6, 7, 8.
8	Cliff Creek Reservoir	do	Lake Fork, Arkansas River			
9	Wilson Creek Reservoir	Fremont	Wilson Creek, Arkansas River		6	
10	Oil Creek Reservoir, No. 1	do	Oil Creek, Arkansas River		4	
11	Slate Creek Reservoir	El Paso	do			
12	West Oil Creek Reservoir	do	do		23	Reservoirs 11, 12, and 13.
13	High Park Reservoir	do	do			
14	Cottonwood Creek Reservoir, No. 1	Fremont	Currant Creek, Arkansas River		11	
15	Cottonwood Creek Reservoir, No. 2	do	do		5	
16	Beaver Creek Reservoir, No. 1	El Paso	Beaver Creek, Arkansas River			
17	Beaver Creek Reservoir, No. 2	do	do		12	Reservoirs 16, 17, 18.
18	Middle Beaver Creek Reservoir	do	do			
19	Seven Lakes Reservoir	do	do		2	
20	Yorkville Reservoir	Fremont	Oak Creek, Arkansas River		6	
21	Big Turkey Creek Reservoir	Peublo	Big Turkey Creek, Arkansas River		4	

22	Six-mile Creek Reservoir	Fremont	Six-mile Creek, Arkansas River		7	Reservoirs 22 and 23.
23	Eight-mile Creek Reservoir	do	Eight-mile Creek, Arkansas River		5	
24	Upper Clear Creek Reservoir	Chaffee	Clear Creek, Arkansas River		4	
25	Cottonwood Lake Reservoir	do	Little Cottonwood River			
	Total				185¼	

UTAH.

1	Utah Lake	Utah	Jordan River, Salt Lake			All lands situate within 2 statute miles of lake at high water.
2	Gunnison Reservoir	San Pete	San Pitch River		5	Do.
3	Bear Lake Reservoir	Rich Bear Lake †	Bear River, Salt Lake		(‡)	
4	Deseret Reservoir	Millard	Sevier River		6	
5	Cottonwood Creek Reservoir	Salt Lake	Cottonwood Creek		14	
6	Panquitch Hayfield, Upper Reservoir.	Garfield	East Fork, Sevier River		8	
7	Plateau Valley Reservoir	do	do		5	
8	Panquitch Lake Reservoir	iron	West Fork, Sevier River		14	
9	Marysvale Reservoir	Pi Ute	Sevier River		11	
10	Otter Creek Reservoir	do	East Fork, Sevier River		12	
	Total				§75	

NEW MEXICO.

1	Lake Constance Reservoir	Dona Ana	Rio Grande		252	Seven townships.—All public lands on the right bank of the Rio Grande between the Mexican boundary and a point 20 miles above that boundary line and extending 4 miles west of said right bank, reserved from entry and sale.
2	San Ildefonso, No. 1, upper site	Bernalillo	do	150,000		§In San Ildefonso and Santa Clara Pueblo Grants.
3	San Ildefonso No. 2	do	do			
4	San Felipe Reservoir	do	do	125,000		Nearly all in San Felipe and Santo Domingo land grants.
5	San Marcial	Sierra	do	360,000	56	35 miles below San Marcial.
6	(Rio Grande)	do	do	140,000	30	On Rio Grande between Rio Palomas and Rio Pirches.
7	Hot Springs (military reservation)	Socorro	Alamosa Creek	35,000	6	Covers good portion of Hot Springs military reservation.
8	Small reservoir, T. 7 S., R. 7 W	do	do		4	
9	Small reservoir, T. 2 N., R. 4 W	do	do		4	
10	Small reservoir, T. 6 N., R. 7 W	Valencia	Rio Colorado, San José River		8	

* Exclusive of Clear Lake. †Bear Lake County, Idaho. ‡ 360 approximately. §Exclusive of Utah and Bear Lakes.

Reservoir sites selected for segregation—Continued.

NEW MEXICO—Continued.

No.	Name.	County.	Basin.	Capacity.	Area segregated.	Remarks.
				Acre feet.	*Sq. miles.*	
11	Group of small reservoirs, four or five, T. 9 and 10 N., R. 12 W.	Valencia	San José River	3,000–4,000	7	
12	Blue water cañon	do	do	20,000	13	
13	Southwest corner T. 13 N., R. 9 W.	Bernalillo	do		11	
14	Northern part of T. 14 N., R. 11 W.	do	do		8	
15	San José River in Laguna Purchase	Valencia	do	12,000		Reservoir in Laguna Purchase.

Total segregations of irrigable lands.

	Acres.
Snake River Basin	11,057,360
Bear River	2,085,320
Upper Missouri and Yellowstone	11,133,440
Owens River Valley	519,000
Rio Grande Valley	5,760,000
Total	30,555,120

REPORT OF PROF. A. H. THOMPSON.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., July 1, 1889.

SIR: I have the honor to submit the following report of the work of the topographic branch of the Irrigation Survey during the fiscal year ending June 30, 1889.

TIME AND LOCATION OF WORK.

Under the appropriation made by Congress for an "Irrigation survey of the arid regions of the United States" funds became available October 3, 1888, and from that date work, either field or office, has been carried on under my direction, and according to plans submitted to and approved by you, in the States of California, Colorado, and Nevada, and the Territories of Montana and New Mexico.

GENERAL ORGANIZATION AND PERSONNEL.

In California, Montana, and New Mexico parties of the U. S. Geological Survey were already engaged in topographic work. These parties were transferred intact to the Irrigation Survey, and additional new parties organized in Colorado and Nevada. Four divisions for the prosecution of work were thus formed, California and Nevada constituting the first, Colorado the second, Montana the third, and New Mexico the fourth.

The charge of work in the Division of California and Nevada was assigned to Mr. H. M. Wilson, assisted by Messrs. A. F. Dunnington, R. H. McKee, Josiah Pierce, jr., and George E. Verrill, as assistants in charge of parties. Charge of the division of Colorado was given to Mr. Willard D. Johnson, with Mr. John W. Hays as assistant. In addition Mr. Anton Karl was given charge of a third party for special work. Mr. E. M. Douglas was given charge of the Division of Montana, with Mr. Frank Tweedy as chief of a party, and Mr. Arthur P. Davis that of New Mexico, with Messrs. R. Henry Phillips and R. H. Chapman as assistants in charge of parties. In all of these divisions work proceeded by atlas sheets bounded by de-

gree, quarter, or half-degree lines of latitude and longitude and conforming in scale and area to the system adopted by the Geological Survey, viz, atlas sheets when on the scale of $\frac{1}{62500}$ to represent fifteen minutes of latitude and longitude each way; when on the scale of $\frac{1}{125000}$ to represent thirty minutes, and on the scale of $\frac{1}{250000}$ one degree.

The field work was usually done on twice the scale intended for publication, the relief being represented by contour lines having equal vertical intervals. The following table shows the locality of work, scale, contour interval, areas surveyed, and present condition of office work for the fiscal year:

Locality.	Scale field work.	Contour interval.	Square miles surveyed.	Condition of office work.
		Feet.		
California	1 inch to 1 mile	100	1,466	Completed.
Colorado	do	50 25	12,650	One-twelfth completed.
Montana	1 inch to 2 miles	200	3,600	Completed.
New Mexico	1 inch to 1 mile	100 50	3,800	Two-thirds completed.
Nevada	do	100	250	Not worked.
Total			21,766	

DETAILED REPORT BY DIVISIONS.

CALIFORNIA AND NEVADA.

At the time of the organization of the Irrigation Survey topographic work was being carried on in central California under the charge of Mr. H. M. Wilson, with an organization consisting of one triangulation and topographic party under his own immediate direction, and two topographic parties under charge of Mr. A. F. Dunnington and Redick H. McKee, respectively. These parties were transferred intact as previously mentioned.

To Mr. Dunnington had been assigned work on what are known as the Jackson and Lodi sheets in California, and to Mr. McKee work on the Chico, Bidwell Bar and Downieville sheets in the same State. It was decided to continue the work of the parties of Messrs. Dunnington and McKee in the areas assigned them.

Mr. Wilson was ordered to proceed with his own party to Nevada, assume charge of the work there in addition to that of California, and directed to organize two additional topographic parties, under charge of Mr. Josiah Pierce, jr., and Mr. Geo. E. Verrill, respectively, and commence work in the areas known as the Carson and Wabuska sheets. Mr. Wilson successfully accomplished the organization and equipment of these parties, and on November 1, 1888, commenced work on the Mount Como range east of Carson City, assuming charge of the triangulation party himself, but at the same

time instructing and directing the topographic parties of Messrs. Pierce and Verrill.

Messrs. Dunnington and McKee completed on November 20 the areas assigned them and were ordered to proceed to Washington, D. C., for office work.

Messrs. Wilson, Pierce, and Verrill completed the survey of 250 square miles on the Carson and Wabuska sheets by December 31. Their parties were then disbanded, and they were directed to proceed to Washington, D. C., for office work.

Early in May, 1889, field work was again resumed in California and Nevada, Mr. Wilson being still in charge with Messrs. Dunnington, McKee, Verrill, and R. H. Chapman as assistants, the latter being transferred from the New Mexico Division. One triangulation and four topographic parties were organized, and work commenced on the Pyramid Peak, Truckee, and Markleville sheets in California, and Carson sheet in Nevada. Early in June Mr. Wilson was transferred to the engineering branch of the Irrigation Survey and Mr. E. M. Douglas transferred from the Montana Division and placed in charge of that of California and Nevada. Under Mr. Douglas's direction the work is progressing satisfactorily.

This division had completed the survey of 1,716 square miles up to June 1, 1889, on the field scale of 1 inch to 1 mile and in contours having a vertical interval of 100 feet.

Topography.—The topography of the area surveyed by the division has varied from the level plains of the Sacramento Valley through the foot-hills region to the crest line of the Sierra Nevada Mountains. The maps produced will show the details of topography, the situation of possible reservoir sites, the approximate location of canal lines, and approximate areas of irrigable lands. The Chico and Bidwell Bar sheets are traversed by streams flowing in deep canyons too far below the general surface of the country to be used for irrigating more than their immediate valleys. Only few sites for reservoirs are here found, and these of limited area.

The Downieville sheet presents broad valleys, wooded ridges and high mountains. On this sheet are many lakes which could be converted into reservoirs, and others could be constructed in many of the valleys. It is thought all the precipitation of this area can be thus stored.

The Jackson sheet is mostly within the foot-hills region ; is traversed by streams running far below the general level of the country, and water to irrigate the uplands must be brought from long distances. Not many sites for reservoirs were discovered in this area.

The Lodi sheet is mostly level or gently rolling country, and lying in the Sacramento Valley can easily be irrigated from the streams traversing it and from storage reservoirs.

The topography of the Pyramid Peak, Truckee, Markleville and

Carson sheets is rugged in the extreme, being largely composed of high, bare mountains, and narrow intervening valleys, but the work has not progressed far enough to make it possible to speak of the topography of these sheets with much detail. A considerable number of reservoir sites have been found, but the irrigable lands are mostly confined to the Carson and Truckee sheets.

COLORADO.

It was decided to commence work in this State at two points, viz., on the South Platte River, near Denver, and on the Arkansas River, near Pueblo. The work in the former area was assigned to the special party under Mr. Anton Karl, and the latter to Mr. Willard D. Johnson, with Mr. John W. Hays as assistant in charge of a party. Both organizations proceeded to their field of work early in October, but such was the labor in organizing and outfitting, that it was late in the month before actual field work could be commenced.

The work assigned Mr. Karl was practically the revision of previously constructed maps of the Denver, and a portion of the Golden atlas sheets. He completed the field work—1,250 square miles—early in December, and was instructed to transfer his field assistants and material to Mr. Johnson, and proceed himself to Washington, D. C., for office work connected with the reduction of his field data.

Mr. Johnson organized two parties, one under his own personal direction, and another under charge of his assistant, Mr. Hays, both for topographic work. The organization and outfitting were completed on October 25, and both parties took the field and, reinforced on the disbandment of Mr. Karl's party by his field assistants, continued work in the plains region of the drainage basin of the Arkansas the entire winter, and until May 1, 1889, without material change.

On May 1, Mr. C. H. Fitch and Mr. Morris Bien were assigned to Mr. Johnson's division as assistants, and he was instructed to organize two additional parties for work under their direction in the mountain region of the Arkansas drainage basin. Mr. Johnson completed the organization and outfitting of his new parties and placed them in the field June 1. At this time he also reorganized the remainder of his force, forming more and smaller parties, in charge of field assistants, and on June 30, 1889, had completed the field work of 11,400 square miles, lying mostly between the eastern base of the mountains and longitude 102° 30′, and latitude 37° and 39°. This area, together with the 1,250 square miles of revision work on the Denver and Golden sheets, makes 12,650 square miles of original and revision work for this division done on the field scale of 1 inch to 1 mile, and in contours having a vertical interval of 25 feet in the plains and 50 feet in the foot-hills regions.

Topography.—The topography of the area surveyed by this division may be classed as of the Plains type throughout. On the Denver and Golden atlas sheets, the valley of the South Platte River forms the most conspicuous feature, traversing, as it does, almost the middle line of this area from south to north, and occupying the lowest altitude. On the west of the river the country gradually rises to the foot-hills of the mountains. The surface of this sloping plain is quite undulating, and sometimes presents broken mesas and narrow valleys. It is drained by Turkey, Bear, Clear, and Rock Creeks. Broad areas of cultivable lands are found, and the irrigator has already appropriated the waters of the traversing streams. A few sites for reservoirs of limited area were discovered. In some cases these might be filled by the storm-waters of the adjacent region; in others, by conducting the stream-waters to them during the non-irrigating season. To the east of the Platte River Valley the surface of the country rises by gentle undulations to the divide between the river and Box Elder Creek. It also gradually increases in altitude from the northern edge of the Denver atlas sheet to its southern limit, thus forming a segment of a bowl-shaped depression, having Denver near its lowest point. This area is drained by Cherry and Coal Creeks and smaller tributaries of the Platte. Large areas of irrigable lands exist, and sites for small reservoirs are quite frequent. A considerable portion of this area is now irrigated by the waters of the South Platte River and Cherry Creek, but many reservoir sites, especially those where storm waters could be stored, were found above the lines possible to be reached from these sources.

The valley of Box Elder Creek, a tributary of the South Platte River, occupies the eastern portion of the Denver atlas sheet. It contains large areas of good irrigable lands. The creek carries but little water except during the winter and spring months. Reservoirs might be constructed in this valley near the southern line of the sheet, but it is thought better opportunities are presented further south and nearer its head.

The immediate valley of the Arkansas River traverses from west to east nearly the central portion of the area mapped within its drainage basin, and forms a dividing line between two areas quite distinct in topographic details. The altitude of the valley is 5,000 feet at the western limit of the work, and 3,750 at the eastern. It is for the most part a narrow plain bounded by well defined bluffs on either side and, lying but a few feet above the surface of the water in the river, can be easily irrigated from that source. North of the Arkansas Valley the country gradually rises from the bluff line to the divide between the Arkansas and the South Platte and Republican Rivers. This slope has its greatest altitude at its western edge, where the front range of the Rocky Mountains rises abruptly from its surface, and decreases to the eastern limit of our work, thus giving a

general slope of the whole area towards the southeast; and this is also the usual course of its drainage lines.

The Fountain, Chico, Black Squirrel, Horse, Adobe, Rush and Big Sandy Creeks are names of the principal water-ways, but only the first is a permanent stream, though the others usually carry water during the early spring months and after the storms of the rainy summer season are often raging torrents. These water-ways have wide valleys with short lateral branches, thus leaving broad gently undulating mesa-like areas between every considerable drainage line. Quite frequently these undulating plateaus do not drain into the adjacent valleys, but into depressions on their surface, forming natural basins or reservoirs. These are most numerous on the Nepesta, Catlin and Las Animas sheets. Some are of large extent. One near Meredith, Colo., having a drainage basin of 40 square miles, has a lake of about 2 square miles in area at its lowest point. Two were noted on the Nepesta sheet nearly circular, about a mile in diameter and at the lowest point 50 feet in depth. Other depressions with outlets need only slight embankments to make reservoirs. There are two sources of water supply: First, the storm water of the region; this is often enormous in quantity, over limited areas a fall of 6 inches in as many hours having been noted by Mr. Hay's party; secondly, from the waters of the Arkansas River, conducted by a high line canal near the crest of the water shed. Almost the whole of this area possesses a deep fertile soil lying at slopes suitable for irrigation.

South of the Arkansas Valley the topography is more broken, but still presents the general features of a great plain sloping toward the north and east, and cut diagonally across by drainage lines having a generally northeasterly course. The extreme western portion of this area reaches well up on the flanks of the Greenhorn Mountains and presents the steep slopes and cliffs and half mesas of the foot-hills region. Farther to the east the central portion of the plain rises in a long gentle swell parallel to, but at some distance from, the Arkansas River. This swell is cut by the southern tributaries of the Arkansas, in canyons sometimes having walls 1,500 to 2,000 feet in height, and bears on its crest a line of mesa-like buttes. The eastern portion gradually decreases in altitude and roughness, slopes more toward the east and merges its mesa-like aspect into the true plains type. There are quite a number of permanent streams in this region, the St. Charles, Huerfano, Apishapa, Timpas, Las Animas and Two Buttes being the principal. These streams are all subject to sudden floods during the rainy season. Throughout the whole area surveyed south of the Arkansas the topography presents many favorable locations for the construction of reservoirs to store both stream and storm waters. In the areas included by the Pueblo, Walsenburg, Apishapa, El Moro, Timpas and Higbee sheets the

streams often cut through the ridges and mesas in narrow canyons, where dams controlling basins of considerable areas could be easily and cheaply constructed. Sometimes these stream reservoirs can be used as settling basins and the waters after depositing their sediment conducted to other basins for storage until used, thus in a great measure preventing the rapid destruction of reservoirs by silting up; a danger of no small magnitude in this region, where in some streams 10 per cent. of the volume of a summer flood may be composed of sediment.

The less rugged topography of the Two Buttes and Springfield sheets also furnishes many opportunities for storm-water reservoirs.

Broad areas of irrigable lands are found everywhere within the limits surveyed by this division. North of the dividing Arkansas Valley the areas are greater in extent and the soil more easily cultivated than south. Only a small portion of the area surveyed is covered by forests. These are mostly on the El Moro, Walsenburg and Pueblo sheets, and the forest growth is mostly composed of cedar and piñon pine. A limited growth of cottonwood also occurs along the streams in other portions, but the uplands bear hardly a forest tree.

MONTANA.

At the time of the organization of the Irrigation Survey topographic work was being carried on in Montana in charge of Mr. Douglas, with Mr. Frank Tweedy as assistant. Two parties were employed: a topographic and triangulation party under Mr. Douglas's personal direction, and a topographic party under Mr. Tweedy. These organizations were transferred to the Irrigation Survey and directed to continue the work already begun on the Dillon, Helena and Phillipsburg sheets. By November 15 an area of 3,600 square miles had been surveyed, completing the two sheets first named and 1,000 square miles on the last, all on the scale of 1 inch=2 miles, and in contours having the vertical interval of 200 feet. Mr. Douglas was then directed to disband his parties and report with his assistant to Washington for office work on the completed sheets.

Topography.—The topography of the area surveyed in Montana is of the mountain type, the whole region being composed of rugged ranges and intervening valleys. The Continental or main Rocky Mountain divide, separating the waters flowing to the Atlantic Ocean from those flowing to the Pacific, passes from north to south through nearly the middle of the Helena atlas sheet, then trends more to the west, leaving the Phillipsburgh sheet on the Pacific slope and the Dillon on the Atlantic. The principal streams on the western slope are Flint Creek in the Phillipsburgh and the Deer Lodge and Blackfoot Creeks in the Helena sheets. These streams flow through considerable valleys, that of the Deer Lodge being about 50 miles long and from 5 to 8 miles wide, while the Flint and Blackfoot, though

smaller, are of considerable magnitude. From these valleys the country rapidly rises in grass-covered foot-hills to the highest mountains. On the eastern slope in the Helena sheet are many small streams flowing from the divide into the Jefferson and Missouri Rivers. The valleys along these streams are generally narrow, with but limited areas of level lands, though the lower valley of Prickly Pear Creek is an exception. The Dillon sheet is drained by the Jefferson River and its upper branches, the Big Hole, Beaver Head and Stinking Water.

Along the courses of these rivers and those of their larger tributaries the level valley lands vary from half a mile to 3 miles in width, and are generally free from forest growth. From these valleys the country rises by broken grassy slopes usually free from timber, and gradually increasing in steepness to the mountains. The mountain ranges throughout the area surveyed generally present steep rocky slopes, bare near the high summits but lower down covered with forests of pine, spruce and fir, and on the still lower slopes grass clad. The highest summits are between 10,000 and 11,000 feet above sea level, and the melting snows usually furnish to the draining streams an abundant supply of water for the valleys below, the most notable exception to this being in the northeastern portion of the Helena sheet. In the upper courses of the streams a few sites suitable for reservoirs were found, but lower down, where the average fall is not more than 30 feet to the mile, numerous parks occur. These might easily be converted into reservoirs. There are also lakes of considerable areas on the Phillipsburgh and Dillon sheets which could easily be converted into storage basins; but where the storage of water is most needed on the Atlantic slope of the Helena sheet but few reservoir sites, and these of very limited drainage area, were found. The valley lands are usually level, easily irrigated from the traversing streams, and, when at not too great an altitude, produce abundant crops.

NEW MEXICO.

In New Mexico the topographic work of the Geological Survey was under charge of Mr. Arthur P. Davis, assisted by Mr. Robert H. Chapman. Two parties were engaged. These were transferred, October 3, to the Irrigation Survey, and a third party, under Mr. R. Henry Phillips, was organized. With some changes of scale and of matters of detail the work already begun was continued on the Santa Clara, Jemez, Albuquerque and San Pedro sheets till January 15, 1889, when all except the San Pedro sheet were completed, work here being suspended on account of the prevalence of small-pox in the towns and the consequent quarantine enforced against all persons coming from the infected districts. On January 15 the parties of Mr. Davis and Mr. Chapman were disbanded, Messrs. Davis and

Chapman being directed to proceed to Washington for office work. Mr. Phillips with his party was directed to proceed to El Paso, Tex., and, commencing in the valley of the Rio Grande near that place, to extend work by atlas sheets northward. Mr. Phillips reached El Paso February 1, and by May 1 had completed the El Paso andLas Cruces sheets. He was then directed to proceed to the San Pedro sheet and complete the unfinished work on that area. He successfully accomplished this June 30, 1889. This division surveyed an an area of 3,800 square miles on the field scale of 1 inch=1 mile and in contours having a vertical interval of 100 feet in the mountain region and 50 feet in the valleys.

Topography.—The topography of three-fourths of the northern portion of the area surveyed may be classed as mountainous; the remaining fourth and the southern area as of the plains type. The northern area comprises the contiguous atlas sheets of Jemez, Santa Clara, Albuquerque and San Pedro. The Rio Grande flows through this area from northeast to south, having for its principal tributaries the Puerco and Jemez Rivers on the west and Santa Fé and Galisteo Creeks on the east. Through the northern third of its course it flows in a deep, narrow, almost impassable canyon, and through the southern portion in a broad, sandy plain, having a general elevation of 5,000 feet.

The Jemez is formed by streams draining the high valleys of Tewan Mountains. In its upper course it flows through narrow canyons, but lower down in a broad sandy plain. Only the lower portions of the Santa Fé and Galisteo Creeks are in the area surveyed, and both here flow across broad plains. The Tewan Mountains occupy the northern portion of the area west of the Rio Grande, their mesa-like summits ranging from 8,000 to 12,000 feet in altitude. Between these summits are broad valleys, having narrow canyon outlets. The draining streams flowing eastward join the Rio Grande, those flowing westward unite and form the Jemez River.

The southwestern or Albuquerque sheet area comprises the broad valley of the Rio Grande and the lava-capped mesas between that stream and the Rio Puerco. East of the Rio Grande the southern portion of the Santa Clara sheet is occupied by the arid Cerrillos hills, low in altitude and irregular in distribution.

The northern part of the San Pedro sheet is occupied by the Ortiz Mountains and the Galisteo Valley. The Sandia Mountain, an immense block, 10,400 feet in altitude, with a nearly vertical western face and a long sloping terrace towards the east, occupies the western portion. Between it and the Ortiz Mountains is the rough, broken San Pedro Valley, extending in the southeastern corner of the atlas sheet onto the Pecos plains. In the high valleys of that portion of the Tewan Mountains drained by the Jemez River are many sites for reservoirs of some considerable area. Along the Rio Puerco, in the

western part of the Albuquerque sheet, are also sites where reservoirs of limited area might be constructed. The Galisteo and Santa Fé Creeks also afford sites, but it is thought that better opportunities occur near the headwaters of these streams. Smaller reservoir sites for the storage of storm waters are frequently found, especially on the San Pedro and Albuquerque sheets and on the southwestern part of the Santa Clara. Indeed, on the sheets named outside of the immediate valleys of the Rio Grande, Puerco and Galisteo, irrigation must be dependent on the storage of storm waters. There are considerable areas of good irrigable lands throughout the whole area, but by far the largest body is within the valley of the Rio Grande, from the Indian pueblo of Cochiti to the southern limit of the work, an area approximately 50 miles in length and from 1 to 4 miles in breadth. The next large bodies are along the Rio Puerco and Jemez River, on the Albuquerque sheet, and on the Pecos plains, in the San Pedro.

FIELD METHODS.

CHARACTER OF WORK.

In the construction of maps for the use of the Irrigation Survey, accurate representation of certain topographic features, within the limits of the scales adopted, was deemed absolutely essential. First, the correct determination of the drainage areas of all streams; second, the correct location of all drainage lines; third, the correct representation of all hypsometric features by means of contour lines representing equal vertical intervals and showing absolute and relative altitudes as well as the angle of slope of all surfaces. Maps so constructed upon proper horizontal and vertical scales show the situation of all reservoir sites of any considerable area, approximate location of possible dams and canal lines, and, with the necessary notes upon the character of the soil, the situation of all irrigable lands, thus giving the construction engineer necessary information upon which to base the details of his plans and estimates for irrigation works.

METHODS OF CONTROL.

The work in all the divisions was conducted by essentially the same methods varying in details only when influenced by local considerations. These comprised a method of determining linear distances or horizontal control, a method of determining altitudes or vertical control, and a method of representing topographic forms.

HORIZONTAL CONTROL.

The determination of the linear distances between points on the surface of the regions mapped was based primarily on the extension of a system of triangulation having sides of considerable length over

the whole area, the length, geographic position, and azimuth of one side of the initial triangle in each system being determined with the utmost accuracy. All the angles of each triangle were repeatedly measured by instruments of precision and the apices or stations permanently marked. If possible at least two stations of this primary triangulation were located on each atlas sheet. Within this system of primary triangles, and depending upon it, a secondary system, either mathematical or graphic, and having sides of lesser length, was developed, and, if necessary, within this second a third system of like character, thus determining the position and distances between a great number of points over the whole area surveyed. In the different divisions the triangulation depends upon different bases. In California and Nevada it was derived from the primary stations of the Transcontinental Triangulation of the United States Coast and Geodetic Survey. In Colorado, it rests both upon the primary stations of the Transcontinental Triangulation of the Coast and Geodetic Survey and upon stations determined by the United States Geological Survey of the Territories, under charge of Dr. F. V. Hayden. In Montana, upon stations of the United States Geological Survey derived from a base line measured at Bozeman, and in New Mexico upon stations of the United States Geological Survey derived from a base line measured at Fort Wingate. From points thus determined in the triangulation all the principal topographic features of the country capable of being repersented on the scales adopted were located on the field-sheet by plane-table methods.

In addition a great many horizontal distances and directions were measured by plane-table traverse methods, using the compass for directions and some form of odometer for distances. These measurements were corrected and adjusted by the accurately determined positions of the triangulation stations. All public roads, all the streams, many drainage lines, cliff edges, valleys, and frequent lines across the country were thus measured, and a complete net-work of accurately determined distances extended over the whole area.

VERTICAL CONTROL.

The altitudes of points in the area mapped were determined by horizontal leveling, angulation, and the use of both mercurial and aneroid barometers. In the use of mercurial barometers stations on the railroad lines running through the country were assumed as bench-marks, and level lines were run from these to places occupied for base barometer stations, and these points were then used as secondary bench or reference marks to which all the barometer and angular leveling of the adjacent atlas sheets was referred. In areas where mercurial barometers were not used, points for secondary bench or reference marks were located by level lines or by angulation, and to these were referred all the angular and aneroid baro-

metric observations. Several of these secondary bench-marks were located on each atlas sheet. When aneroid barometers were used they were compared several times daily with altitudes of known points determined by other methods, and thus a check kept on their errors. The altitudes of all points located by plane-table intersections were determined by angulation.

CONTROL OF REPRESENTATION.

The outlines and details of topographic forms were secured by plane-table work on stations occupied, and by sketches from the stations in the plane-table traverses. This work was done in contours closely located and having a prescribed vertical interval. In some cases, the topographer performed his computations and located his contour lines with precision in the field. In others the contours were located approximately, their final position being determined by the reduction of field observations. Special attention was paid to the correct location of the courses of streams, the outlines of valleys, cliffs, benches and terraces, and the slopes of all irrigable lands.

OFFICE WORK.

Immediately on the disbandment of parties in the field the persons belonging to the permanent force were directed to report to the office of the Geological Survey in Washington for office work in the reduction of their observations and the final plotting and drawing of the maps.

ORGANIZATION.

The office force was organized by giving each chief of a division charge of the office work of that division, and assigning the heads of parties and assistants having charge of separate branches of the work to conduct and assist in the work on that particular area, thus securing in the construction of the maps all the knowledge gained by personal observations in the field.

CALIFORNIA AND NEVADA.

Office work on the California atlas sheets commenced December 1, and continued, under charge of Mr. H. M. Wilson, till May 30, 1889, completing the Chico, Bidwell Bar, Downeeville and Jackson sheets, and part of the Lodi sheet, ready for engraving.

The area surveyed in Nevada being small it was thought best to defer the final plotting of the work until another season ; however, all the data depending upon personal reduction for accuracy were carefully prepared and with the other field-notes filed for use when necessary. On the completion of the office work of this division all persons engaged were directed to proceed to California and Nevada for field work.

COLORADO.

On return of Mr. Anton Karl from the field he immediately commenced the reduction of his observations and the final drawing of the Denver and a portion of the Golden atlas sheets. He completed the work ready for engraving early in April and was then transferred to work in the Geological Survey. No office work has been done by the parties under charge of Mr. W. D. Johnson.

MONTANA.

Office work on the Montana atlas sheets was commenced, under charge of Mr. E. M. Douglas, December 1, 1888, and continued until May 15, 1889, completing the Helena and Dillon sheets and 1,000 square miles on the Phillipsburg sheet ready for engraving. On the completion of the office work Mr. Douglas was transferred to the charge of the California and Nevada Division, and Mr. Tweedy directed to proceed to Montana for field work.

NEW MEXICO.

Office work on the New Mexico atlas sheets was commenced February 1, 1889, and continued under charge of Mr. Davis till June 15, 1889, when the Jemez, Albuquerque and Santa Clara sheets were completed ready for engraving. On account of the incomplete condition of the field work on the San Pedro sheet it was decided not to attempt its final drawing, but the data was finally revised and filed for future use. On May 1, Mr. Robert H. Chapman completed the drawing of the maps upon which he had conducted field work. He was then transferred to the California and Nevada Division and directed to proceed to Nevada for field duty. On June 15, Mr. Davis was directed to proceed to New Mexico and again assume charge of field work, leaving no office force at present engaged in Washington.

I herewith transmit maps of California, Colorado, Montana, Nevada and New Mexico, showing areas surveyed by the difierent divisions during the fiscal year. I also transmit a detailed statement, (Appendix A) of the amount expended in the prosecution of the work under my charge for the fiscal year ending June 30, 1889.

I am, very respectfully, your obedient servant,

A. H. THOMPSON,
Geographer in charge.

Hon. J. W. POWELL,
Director U. S. Geological Survey, Washington, D. C.

REPORT OF CAPT. C. E. DUTTON.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., Nov. 1, 1889.

SIR: The passage of the sundry civil bill on October 2, 1888, appropriating $100,000 for surveys relating to irrigation, devolved upon this bureau a new kind of work and one full of difficulties. The first step was a determination of the character of the work which would be required to carry out the law, and the second was to organize it. In order to ascertain the extent to which the arid lands of the West are capable of being redeemed by irrigation, to select reservoir sites, and to segregate irrigable lands four inquiries are necessary: First, what is the available water supply; second, what lands are cultivable; third, in what practical way can water be brought to the cultivable lands; and, fourth, where are the reservoir sites, and what is their character and capacity?

The inquiry as to the available water supply seemed to you separable from the other inquiries and for this investigation it was decided to employ a special class of men. The selection of irrigable lands, the investigation of methods of irrigating them, and the selection of reservoir sites required the services of men skilled in the special branch of engineering which deals with works for irrigation. Thus two lines of inquiry were suggested, one being of a hydrographic, the other of an engineering character. The organization contemplated by you, therefore, embraced a corps of hydrographers and a corps of irrigation engineers. Of the topographic work deemed an essential part of the inquiry, I do not speak, as it is under the charge of another division officer.

HYDROGRAPHIC WORK.

The investigation of the amount of water available involves several subordinate inquiries: First, the amount of water flowing in the streams, and the variation throughout the year; second, the probable amount available for catchment in storage reservoirs; third, the probable amount of loss from reservoirs by evaporation; fourth, the duty of water, i. e., the amount of land which a given quantity may be made to irrigate.

The measurement of water flowing in a stream is not an easy matter. It requires skill and rather costly instruments. While the general method has been the subject of much inquiry by a few men, and has been practiced to a small extent, there is a wide variation in details and considerable uncertainty or discordance in results. At the beginning of the organization there were no men available who possessed the requisite experience and skill except two or three men

who were occupying responsible positions, and it was doubtful if they could be induced to relinquish them. Neither were any instruments to be found in the market as articles in regular supply, and such as were needed must be made to special order. The investigation of the amount of water available for catchment required the opening up of an entirely new field of research. The measurement of the loss by evaporation was an equally novel subject and full of difficulties.

The duty of water has been investigated carefully in other countries and to a very limited extent in our own, and much valuable information was accessible on this subject in printed form. But unfortunately the results in one locality are not available except in a very rough and unsatisfactory way in the effort to infer the duty of water elsewhere. Every region is a law to itself in this matter, and the duty varies largely in localities which seem to be similarly circumstanced. In view of the novelty of the work thus devolved upon the survey, of the impossibility of finding men skilled in the work required, of want of instruments adapted to the work, and in further view of the fact that the winter was near at hand, during which the field work would, in most portions of the West, be impracticable, it was deemed best to select a small body of young men of good education and high general intelligence and establish them at some advantageous station where they could, in the course of the winter months, acquire a knowledge of the methods and instruments they would have to employ. Fourteen young men were carefully selected and were placed in a camp of instruction, situated at Embudo, on the Rio Grande River, about 50 miles north of Santa Fé, in New Mexico, where they passed the winter in practicing with the various instruments selected for trial and in becoming familiar with the theory and practical application of the methods. In the month of April the camp was broken up and the men distributed to their respective fields of work.

The camp of instruction at Embudo was placed in charge of Mr. F. H. Newell, and the work required of the men consisted in practicing stream gauging by various methods, measuring the rise and fall of the stream from day to day, measuring the daily evaporation, and making observations with meteorological instruments.

STREAM GAUGING.

In measuring the flow of streams, it is to be remembered that the flow varies from time to time. The measurement made on any given day while the river keeps a steady flow for an hour or two, is good only for that day and hour, and for times when the river is at the same stage. A small rise in the stream is accompanied by a large increase in the flow, and a small fall by a large decrease in the flow. To ascertain the flow during a considerable period of time and thus obtain an average for varying stages, two distinct classes of measurement

are necessary: First, the amount of flow corresponding to each and every stage; second, a continuous record of the rise and fall.

(1) *Measurement of flow.*—There are four methods of gauging the flow of a stream: (*a*) by weirs; (*b*) by floats; (*c*) by formula; (*d*) by meters.

Weirs are practicable and economical only in the case of small streams at low water, and in such cases the system is preferable to all others. When the depth of the water passing over the weir much exceeds a foot it becomes sometimes uncertain. In streams not exceeding 25 to 30 feet in width, and carrying not more than 40 or 50 cubic feet of water per second, a weir may be constructed quickly and cheaply. It is almost certain to be swept away by high water, but if small and in shallow water it can be easily replaced. It is desirable, however, to select stations where the water above the weir has no sensible "velocity of approach" other than that produced by the constant movement of water over the weir, as it is difficult to make proper allowance for it.

Gauging by floats is the crudest and most unreliable of all methods. It consists in throwing floating objects into the water and noting the length of time occupied by the float in moving through a measured distance down the stream. The distance divided by the time is the mean velocity of the motion of the float. But this velocity of the float is not the mean velocity of the stream, which varies in different parts of the width and at different depths. As a rough and ready rule the mean velocity of the stream is taken to be about four-fifths the velocity of the float. This is no doubt a fair approximation where the cross-section of the stream is symmetrical, the current smooth, regular and free from eddies, and its course free from obstructions. But in small or medium-sized rivers such conditions are rare and the whole method of measurement is liable to great uncertainties and it is impracticable in large rivers.

Gauging by formula is based upon the assumption that with a given cross-section the mean velocity of flow bears a certain ratio to the declivity down which the water moves. The declivity may be accurately ascertained by the spirit level. With a given declivity the flow will vary with the cross-section, being greater when the latter is narrow and deep than when it is broad and shallow. The effect of the form of the cross-section has been experimentally investigated by several hydrographers and an empirical formula has been devised for it which seems to give very fair results when the cross-section is not of very irregular form and when the bottom is not incumbered with large stones and other obstacles. In general, however, it is of very limited utility.

Gauging by meters is the most satisfactory and complete method of all. The ordinary current meter is a small wheel which is caused by the current to revolve when immersed. It may be of propeller,

windmill or anemometer form. The axis of the wheel is attached to some device for recording automatically the number of revolutions. It is necessary to know the number of revolutions in a unit of time which corresponds to any given velocity; in other words, every meter must be "rated." In all good meters the number of revolutions bears a simple ratio to the velocity of the stream unless the velocity is very small. At very low velocities, say less than a foot per second, even the best known form of meters become irregular and uncertain. They are also inferior to weirs for very small or very shallow streams. In gauging with a meter, the cross-section of the stream is subdivided into portions 5 feet wide in ordinary streams and 10 feet wide in very broad ones. The form of the bottom and areas of subdivisional cross-sections are ascertained by soundings, and the mean velocity of each is measured with the meter. Each subdivision is therefore treated as a separate stream and the flow of the entire stream is the sum of the flows of its constituent parts.

In order to compute the flow of a river through a considerable period of time during which its volume of flow varies, it is necessary to gauge it at its extreme stages, both high and low, and also at intermediate stages. Gaugings at five or six stages will be sufficient for a river between well-defined banks which it does not overflow. A very close approximation can then be made to the flow at any intermediate stage which has not been gauged. It is further necessary to keep a continuous record of the rise and fall of the stream throughout the entire period for which the flow is to be estimated. With this record and with the gaugings at the proper stages, we shall have all the data necessary for computing the flow through the entire period while the record is maintained, and for ascertaining how the flow varies from day to day and from month to month.

(2) *Record of fluctuations.*—There are two methods of conducting these observations. The first of the methods is as old as civilization. Herodotus mentions the scale by which the ancient Egyptians measured and recorded the rise and fall of the Nile. He called it the nilometer. I have not thought it worth while to change so good and so old a name for an identical device for an identical service. The nilometer scale is simply a strip of board painted white with feet and inches graduated upon it. The lower end is placed in the stream so as to be immersed at low water. It may be vertical, or, still more conveniently, inclined; in which latter position it can be more easily secured with firmness to the bank of the river. One thing more is quite essential. The position of the zero mark of the scale must be accurately determined with reference to some permanent point or bench-mark in the close vicinity, so that the scale may be relocated when disturbed by the floods, as it is sure to be. This scale may be visited twice or thrice daily by an observer and record made of the height of the water on the scale.

The second method of observation is by means of an instrument which records the fluctuation automatically. A chronograph drum is revolved by clockwork, making one revolution a week. A sheet of profile paper is wrapped around the drum. A pencil or glycerine pen has its point resting on the paper. The frame which holds the pencil runs on a slide parallel to the axis of the drum. The pencil frame has a fine wire attached to it, which goes over a pulley and down into a well, where its end is attached to a float. The water in the well is connected with the water in the river by an open pipe, and rises and falls with it. Thus the motion of the float up and down is transferred to the pencil which traces a curve on the paper correspondingly.

In such a country as the West the conditions are favorable to a very high rate of evaporation. The summer heat is intense and the dryness of the air extreme. In estimating the efficiency of a storage reservoir the loss of water by evaporation is always important, and in some cases is so serious a matter as to render valueless contemplated reservoirs which otherwise might have been of the greatest value. There are many instances in which the question whether a site be advantageous or not for reservoir purposes depends upon the probable loss by evaporation. This is always the case in large lakes whose inflow is relatively small, like Clear Lake and Tahoe, in California, Utah Lake, Flathead Lake, and many others. If the annual evaporation exceeds a certain limit, and one which is not very improbable, the lake is of no value as a reservoir. If it falls below that limit, every inch below means water enough to irrigate several thousand acres of land. Many other considerations might be brought forward to illustrate the high importance of the subject. It is a very serious matter in canals and rivers, and in the distributive systems by which water is carried from main canals to the lands. It is, moreover, a subject on which there is great uncertainty. It is not easy to measure the rate of evaporation from water surfaces as they exist in nature. To fill a vessel with water, place it upon the ground or upon a table and measure the daily loss, is far from meeting the requirement, for the evaporation from such a vessel is not comparable with that from a lake or reservoir. There are four factors which enter into the problem. The rate of evaporation depends (1) upon the temperature of the water, (2) the temperature of the air, (3) the relative humidity of the air, and (4) upon the wind. If a vessel is used it will also depend upon the form and size of the vessel and the depth to which it is filled.

In order to approximate the conditions of observation as near as possible to those of the body of water whose rate of evaporation is to be measured, it is necessary in the first place to keep its temperature as nearly even with it as possible. No better way has ever been suggested than to float a thin metallic evaporating pan in the water

and keep it as nearly full as may be without danger of water slopping in or out. The difficulty, however, is that the portion of the vessel's rim above water prevents the full action of the wind. Experiments with similar vessels unequally filled show a much greater loss from the fuller vessel ; the conditions being otherwise identical. Moreover, on large bodies of water there are waves which must affect the rate of evaporation, while within the vessel waves are not considerable. They would be fatal to the experiment if they were.

As soon as notice was received that the appropriation was available measures were taken to secure competent men for the hydrographic work and to determine the instruments to be employed, methods of use, and forms of reports to be made. Two or three weeks were thus occupied and early in November Mr. F. H. Newell and Mr. J. B. Williams were sent to New Mexico to select a place for a camp of experiment and instruction. They decided upon Embudo, on the Rio Grande, about 40 miles above Santa Fé, and as soon as preparations were made for a reasonably comfortable winter camp the hydrographers were all sent there. Mr. F. H. Newell was placed in charge of the camp and proved to be a highly efficient officer. As the hydrologic work is closely interwoven with facts dependent upon meteorologic data it was deemed necessary that the men should become proficient in observations of that class. A large amount of such data would require treatment and investigation in this office and a skilled meteorologist was required for that purpose. Prof. George E. Curtis, of Washburn College, Topeka, formerly in the United States Signal Service, was selected for this purpose and for the time being was sent to Embudo, where he proved himself a most intelligent and capable instructor.

The object of this camp was to train the new members of the hydrographic division for active and independent field work for the succeeding seasons. The principle under which the operations at the camp were conducted was to attempt all those investigations which seemed pertinent to the future work of the Survey, modifying from time to time the methods and instruments as experience developed obstacles or objections.

A regular routine of observations was begun and carried on by which each man in turn became familiar with the details of each investigation ; but beyond this the fullest possible scope was left for individual development, and opportunity for original work in such lines of research or study as each should choose.

The work was classified into :

Measurement of river flow.
Measurement of rain-fall and general meteorology.
Measurement of evaporation.
Measurement of matter carried in suspension by water.
Topographic details of river courses.

These operations were continued through the winter with the following results:

MEASUREMENT OF RIVER FLOW.

A small rope ferry was established near the camp across a suitable part of the river and various forms of meter used for obtaining the velocity. Changes and improvements in the meters were suggested while experience was being acquired.

From the results obtained by the meters the velocities in various parts of the river's cross-section were determined and both horizontal and vertical curves of velocity were plotted, making a comparative study under various conditions.

While meters were being used at one part of the river, other methods of stream measurement were tried at suitable points, i. e., by surface floats, subsurface floats, and vertical rods. Comparisons were made between the results obtained in these various ways as well as by the formula for river flow given by Kütter.

Records of the river height were kept continuously and a study made of the relation between river height and discharge. These records were kept both by observation and by an automatic recorder or "nilometer" which was installed and tested as to the suitability for this work.

After sufficient practice was had at stream gauging in the vicinity of camp, small parties were sent out to measure the river and tributaries both above and below, a distance of 50 miles or more, each party being gone for several days or a week at a time. This gave the men practice not only in the actual work of stream measurement, but also in outfitting a field party for this purpose and in establishing gauging stations under difficulties.

METEOROLOGY.

The camp was fully equipped with meteorological instruments, including barometers, maximum and minimum thermometers, psychrometers, rain gauges, thermograph, and sunshine recorder. These instruments were under the charge of Prof. Curtis, a skilled meteorologist.

The men were detailed by daily or weekly turns to observe and keep the records of these various instruments and received the necessary instruction supplemented by general lectures by Prof. Curtis on the care and use of instruments, so that each should be able to establish observing stations and direct the ordinary observers.

An attempt was made to predict the probable flow of the river for the succeeding summer, by obtaining through volunteer observers the amount of snow in the mountains.

EVAPORATION.

The measurement of the amount of evaporation from water surfaces, as in rivers and lakes, was undertaken by means of floating metallic pans. These were kept nearly full of water and the amount evaporated noted at regular intervals by a small inclined brass scale, suspended in the center of the pan.

Various substitutes for this scale were tried and rejected in favor of the simpler though more crude device. Comparisons between pans in different localities and under various conditions were begun and some valuable experience acquired, especially in the details of locating and managing the pan.

SUSPENDED MATTER.

Several series of experiments were made as to the most practicable method of attacking this subject, the limitations set being that the apparatus should be simple, strong and portable.

The method followed was to collect a sample from the river in a small vessel of known capacity, allow the earthy matter to settle, decant the clear water, filter the sediment dry, and weigh.

The two matters of prime importance were: First, taking the sample; second, drying the filtrate.

First. For obtaining the sample from flowing water a horizontal sediment trap, with vertical doors at each end, was tried and comparisons were made between the samples taken by that method and by means of bottles. The bottles were so arranged that the stoppers could be withdrawn and replaced under water.

The conclusion reached by a study of the results obtained in these comparisons was that the bottle was preferable if properly used, i. e., the stopper being drawn and immediately replaced when the bottle filled; the reason being that with no transfer of the sample there is no change of loss, and the bottles, moreover, can be packed up or put away until the sediment comes down or to await the convenience of the operator.

Second. Drying the sample to a constant weight was a difficult operation in camp. Water-baths were tried and various devices, all being discarded in favor of a carefully closed sand-bath, with separate compartments for filter papers in various stages of moisture and heated to a constant temperature by a small oil stove.

Comparative tests were begun between the sedimentary load in different parts of the river's cross-section to determine if possible at what portion the best representative samples could be taken.

TOPOGRAPHY OF RIVER CHANNEL.

This included a general study of the whole river in a broad way as to its habits and peculiarities and also a more particular ex-

amination of the places at which river gauging should be undertaken.

Practice was had in making small contoured maps and cross-sections of river bottom and sides, and comparisons were made of the changes occurring from time to time, throwing much light on the difficulties encountered in calculating stream discharges.

After the close of winter the camp of instruction at Embudo was broken up and the hydrographers were assigned as follows:

Arkansas River	Robert Robinson.
Rio Grande in New Mexico	Geo. T. Quinby.
Rio Grande at El Paso	H. M. Dyar.
Gila and Salt Rivers	W. A. Farish.
Sacramento Valley	W. P. Trowbridge, jr.
Carson and Truckee Rivers	Frank Harrison.
Utah Territory	F. H. Newell.
Do	T. M. Bannon.
Snake River Basin	J. B. Williams.
Do	L. D. Hopson.
Upper Missouri	R. S. Tarr.

SUMMARY OF WORK.

The following summary of the work begun and carried forward in the several districts is submitted:

ARKANSAS RIVER.

Mr. Robertson began operations for measuring the flow of this stream. A good station was found at Canyon City where the river emerges from the mountains and was speedily established. A nilometer scale was placed and an observer secured to record twice daily the fluctuations of the river. Gauging was also begun, though the annual rise had not taken place. It was thought desirable to establish similar stations lower down the stream at intervals of 30 or 40 miles, but good sections for observing stations were not easy to find. Soon after leaving the mountains the Arkansas becomes a broad and shallow stream with a loose sandy bottom which changes much from time to time and is liable to great changes after any storm or heavy shower. These are comparatively frequent in the summer months. Three stations, however, were selected—one just above Pueblo, another near La Junta, and one near Lamar. The total length of river between Canyon City and Lamar is about 165 miles.

Stations were also established on the Huerfano at Hermosilla and on the Purgatoire at Las Animas. These are two tributaries of the plains entering the Arkansas from the south. At times they carry large bodies of water, though at ordinary stages they are small streams. From the gaugings and nilometer records made at all these stations tables of daily mean discharge have been constructed and graphically plotted.

RIO GRANDE RIVER.

The observations begun at Embudo in December and continued through the winter by the camp of instruction were maintained after the camp was broken up. Another station was established on this river at Del Norte, in the San Luis Valley, which gives the amount of water entering at that point. A station was also established on the Jemez River, which enters the Rio Grande from the west near Bernalillo. At El Paso a first-class station was established for carrying on gauging, nilometer records, the measurement of evaporation and of the sediment brought down by the river. Mr. Quinby placed about forty rain-gauges with carefully selected observers with a view of obtaining information of the rain-fall of particular localities when such information was specially needed.

GILA AND SALT RIVERS.

These rivers offer the greatest difficulties to hydrographic study of any which have been attempted during the year. While the same difficulties are present to some extent in others they are elsewhere less formidable. They arise from the peculiar character of the stream beds which afford no good cross-sections for measurements, and also from the absence of facilities for carrying out any work that may be attempted. The latter difficulty is due to the scarcity of settlers and the great distance of the stations from sources of supply. It is not easy to secure men who are willing to banish themselves for months at a time from all human intercourse and remain alone in one of the most cruel deserts in the world merely to watch the rise and fall of a river. The state of the appropriation would not warrant the employment of relays of men at high wages for this purpose. Self-recording instruments are not practicable at any place thus far found to be available for gauging, owing to the shallowness of the streams and the unstable character of their channels. Mr. Farish, however, with rare energy and devotion has done much in grappling with these difficulties. Three stations have been established by him: on the Gila about 14 miles above Florence, on the Salt a little above the junction of the Verde, and on the Verde near the latter locality. Continuous records have been maintained and repeated gaugings made. About forty rain-gauges have been placed in various localities in Arizona whence observations are specially desired and needed. An evaporation station has been located at Tempé, where the correlated meteorologic observations are maintained.

TRUCKEE AND CARSON RIVERS.

Mr. Harrison began work in these rivers in April by a preliminary reconnoissance for the purpose of selecting stations and gaining the knowledge of the basins necessary for attacking the problems. Great

difficulty was experienced in finding suitable cross-sections owing to the torrential character of the streams and to many obstructions presented by dams and other obstacles caused by the use of these rivers for floating logs, lumber, fire-wood and railroad ties. The season also was unfavorable. An exceptional storm in May caused the river to rise prematurely and before that event was expected and before the stations had been fully established. With the exception of this storm the season was almost unprecedentedly dry and after it was over the river quickly fell, so that in some of them the record of river heights became unsatisfactory because there was so little water to measure. Stations, however, were established at Essex, Nev., and a record kept by which the daily mean discharge has been calculated from May 21. The flows of the tributaries were also gauged repeatedly in Prosser, Juniper, Grey, Bronco Martis, Squaw, Coldstream, and Dog Creeks, and on the Little Truckee. The Carson River was examined and gauging begun in June near Genoa, and on the west fork of the Carson below Hope Valley.

HYDROGRAPHIC WORK IN UTAH.

In April Mr. Newell was sent to Utah to make certain examinations of Utah Lake with reference to its capacity for a reservoir site and to furnish the specifications for its withdrawal as such under the law, so far as the lands covered or overflowed by it or the lands bordering upon it were still public lands. Having completed this work it became evident that his services for hydrographic investigation were so urgently demanded and so greatly needed that it seemed as if no more useful station could be selected. He was therefore instructed to begin the gauging of the principal streams and to carry on systematic hydrographic work in those portions of the territory which were readily accessible. Beginning with the Bear River, a station was located at the lower end of the canyon where it enters Malade Valley, and one has since been placed above Cache Valley at Battle Creek. At all of the principal streams which flow from the Wasatch into the Salt Lake basin observations and gaugings have been begun, including Provo River, American and Spanish Forks. Stations were established and gauged in the fertile Sevier Valley at Joseph City and at Leamington. An evaporation station has also been well maintained at Fort Douglas. Mr. Newell has also collected a large amount of statistical information concerning the water-supply, canals and irrigation of Utah, and accomplished the segregation of the irrigable lands in Bear River valley.

SNAKE RIVER.

Mr. J. B. Williams was assigned to the hydrographic work in Idaho, with Mr. L. D. Hopson as an assistant. Prior to this assignment he had been sent to El Paso to establish the important station there, and

did not reach Idaho until the middle of June. For gauging the Snake a station was selected at Eagle Rock, on the Utah and Northern Railroad. The river channel is here 510 feet in width. A wire cable was stretched across it and a large flat-boat constructed. The first gauging was accomplished July 19, showing a flow of about 4,660 second feet, the river being then past the flood-time and rapidly approaching its lowest stage. Numerous gaugings at successively lower stages were made here. Much water was being taken out above Eagle Rock and Mr. Williams visited all the canals in active use, estimating by careful measurement the water diverted, which amounted to about 1,100 second feet. He also gauged the forks and tributaries of the river, six in number, to estimate their separate flows. Earlier in the season Mr. Hopson visited the Wood River, establishing two gauging stations. Continuous observations of the rise and fall are kept on the Snake and on Wood River.

YELLOWSTONE AND UPPER MISSOURI.

Mr. Williams, after establishing his stations in Idaho, went to Montana to take the place of Mr. Tarr who had resigned. He located two stations on the Yellowstone—one at Springdale and the other at Horr—one on the Missouri at Canyon Ferry, one on the Gallatin near Bozeman, one on the Madison 20 miles above the forks of the Missouri, one on the Jefferson 15 miles above the forks, one on the Sun River 18 miles above Augusta, one on the Téton River near Choteau, and one on the Dearborn near the town of the same name. Repeated gaugings were made at most of these stations and observations begun on the rise and fall of the rivers. Evaporation pans were established at Springdale, Hogan, Great Falls, Bozeman and Livingston. The year was most exceptionally dry and the rivers correspondingly low. The Yellowstone in August carried at Horr 1,553 second feet on the 26th of August, and at Springdale 2,111 second feet, which is about as low as it may be expected to fall in any season. The Missouri at Canyon Ferry carried 1,643 second feet on the 29th of August, and the Madison 1,104 feet on the 17th.

GENERAL REMARKS ON HYDROGRAPHIC WORK.

The observations made on the rise and fall of rivers and the gaugings at various stages have not all been reduced to final results as yet, but at the present time this is being done with as much rapidity as possible. During the field season and the opening of the work the hydrographers were fully occupied in establishing their stations and getting them in order. As these stations are generally far apart much time was required to "make the rounds." The gauging work is tedious and laborious; skilled men are not to be had, and almost every detail of drudgery, both physical and mental, falls wholly upon

the hydrographer. All things considered, the result of the first season's work is quite as good as could be expected. About one-half the rivers of the arid region are now under surveillance, and with the experience gained the other half can be put in the same way much more readily and expeditiously.

Some of the difficulties in the way of hydrographic work have been proved to be even more serious than was anticipated though the anticipations of them were serious enough. By far the worst is the difficulty of getting observers to record the rise and fall of the streams. In nine cases out of ten it will happen that the cross-section at which it is practicable to make good records is situated at a considerable distance—often many miles from any human habitation. As the cross-section can not be brought to the observer the observer must go to the cross-section. He must go twice daily on foot or on horseback. He can be paid for his trouble but there is no guaranty that he will do the work. It is a simple matter to write down on the printed form the same river height to-day that was read yesterday without taking the trouble to go to the station and the false entry may escape detection. It is gratifying, however, to be able to say that very few cases have been found in which this trick has been suspected, and the skilled hydrographer soon acquires the faculty of detecting it when the falsified reports come in. Even with conscientious observers the routine soon becomes tiresome and many of them discontinue their records without sufficient notice of their intentions. Several records which would have been good if continuous, have been interrupted from this cause at critical stages, to the great vexation of this office.

This want of a reliable corps of observers and the difficulty of finding them on the ground brings into view the necessity of some self-recording device. Such an instrument has been in use in Colorado for several years and the results obtained are understood to be fair. One of the troubles is that the instruments are liable to be meddled with by the curious and destroyed or stolen by the malicious. They are also liable to derangement of their working, especially at high water, the time when their records are most important. If some device could be obtained by which the rise and fall could be transmitted electrically to the observer's house the expense of maintenance would be minimized, and the record would quickly indicate any derangement of the apparatus, which might be remedied in an hour or two. A mere mechanical device might fail to work an hour after it was left and the failure remain unknown for a week. Serious attention will be given to the problem of finding some electrical device for such records, as well as to the improvement of self-recording mechanical devices.

MONTANA DIVISION.

It was decided that the work in this State should be chiefly of a reconnoissance character. Although irrigation is as necessary here as in other States the progress made has been comparatively small, for settlement upon a considerable scale is very recent. The water supply of Montana was known to be large and the northeastern and eastern part was known to possess very great areas of arable land. Some of the rivers traverse the plain portion of the State in rather deep troughs which would render necessary costly works to divert the waters; but to what extent this might be the case was not foreseen. The waters in the rivers must certainly be insufficient in their present condition to irrigate the great areas of good bench lands and the question arose as to the part which storage reservoirs must play in the highest and best development of the future. On these subjects little was known. Mr. Wilson, who was assigned to this division, took the field about the 1st of June. After a brief reconnoissance he was of the opinion that among the most interesting problems in the State would be the utilization of the waters of the Yellowstone and Sun Rivers. Both of them after leaving the mountains run in deep troughs through the plains with very little bottom land, so that their utility, if realized at all, must be obtained by bringing them upon the bench lands. Both of them had facilities for storage and a study of them would throw more light upon the possibility of a high development than that of any other stream. He was authorized to make a detailed examination of the Sun River drainage; not merely for ascertaining the capacity of the river itself, but also as a typical example of a stream which requires for its development a long diversion line. A field party was therefore outfitted and placed in charge of Mr. J. B. Rogers, an assistant, who at the close of the fiscal year was just beginning the survey of the Sun River basin. Mr. Wilson proposed to occupy the greater part of the summer in continuing his reconnoissance, in searching for reservoir sites and for data upon which to segregate irrigable lands. At the time of writing this report the field season has closed and the retained men are engaged in the office work, preparing their results for record and action. These results are very satisfactory, but as they are not as yet sufficiently worked out in the office for formal presentation in detail, nothing beyond a brief summary will here be given.

A preliminary survey of the Sun River basin has been completed, resulting in the definite location of nine reservoir sites along the course of the river, whose united capacity will be about 143,000 acre feet. The dam sites of these reservoirs have been surveyed in sufficient detail to enable an estimate to be made of the quantity of material required to construct them and to assign the proportions of the dams whenever the materials and methods of construction are deter-

mined. The flow of the river during the summer season has been gauged. The last summer was one of very low water throughout almost the entire West and may be taken as representing the minimum flow for any year. The gaugings showed a mean flow of the Sun River during the months of July, August, and September of about 200 second feet. The winter and spring flow of the river is believed to be more than sufficient to fill all the reservoirs.

A line of level and traverse has been carefully run along the bluff on the north side of the river from the lower dam site a distance of 80 miles, the diversion line being about 41 miles long, and emerges upon the bench lands above where it can be made to command more than 300,000 acres of the best agricultural land. This area is probably much greater than the entire summer flow and storage can irrigate. Approximate estimates of costs can be made from this survey. Undoubtedly the cost would be considerable and in the present condition of settlement and of land value it is doubtful if it would be warranted. But with time and increasing population water rapidly rises in value, and in the new West the cost of construction greatly diminishes, and in the course of a very few years all such doubts may resolve themselves into an affirmative answer.

Mr. Wilson also examined in a preliminary way the practicability of diverting the Missouri River in the Missouri Valley which has a large amount of good agricultural land. Near Toston, about 40 miles this side of Helena on the Northern Pacific road, a very short diversion line would carry the waters of this river to the lands, and no serious difficulties presented themselves. A survey of this locality seems desirable.

Further up the stream, at the foot of Gallatin Valley, the Missouri breaks into three forks—the Gallatin on the east, the Madison in the middle, and the Jefferson on the west. The Gallatin and its branches have for some years been used for irrigation, and the important town of Bozeman has owed its prosperity in a large measure to the resulting agriculture. It is, however, a rather small stream at low stages and the use made of it is attributable to the ease with which it could be diverted. The Madison is a very much larger stream, carrying at low stages over 1,100 cubic feet per second, while the Jefferson at low water has only about 200 feet. Along the courses of these rivers there is a considerable amount of agricultural land, and near their sources Mr. Wilson found many basins which seemed capable of being converted into reservoirs The forks of the Missouri offer a problem worthy of investigation. It would appear, however, even at the present stage of the inquiry, that whatever uses are made of the upper Missouri must be accomplished by diversions above Great Falls. Here the river cascades at once into a deep gorge with abrupt rocky walls from which it could not be taken by canals, and the trough

of the river maintains that character for an indefinite distance below. In the Missouri Valley above Great Falls the river carries at the lowest stages 1,600 to 1,800 feet of water, an amount which is not sufficient to serve all the good lands which could be brought under canals. But this supply can be greatly augmented by storage.

Careful attention was given by Mr. Wilson to the subject of water storage. The facilities for it were found to be considerable. The most extensive basins he found were in the Yellowstone Park, the largest of all being the lake itself. Yellowstone Lake in fact is the most effective reservoir site of which we have any knowledge at present. It is also one of cheap construction. Its probable delivery will exceed considerably a million acre-feet of water, sufficing to irrigate more than a thousand square miles of land. How to utilize such a vast body of water would be one of the noblest of engineering problems. Still other basins of large capacity, though collectively but a moderate fraction of that of the lake, occur in the Yellowstone drainage—most of them in the Park. In the Madison drainage also numerous large reservoirs were found whose collection capacity will probably exceed 800,000 acre-feet, and in the Jefferson Valley storage capacity of quite equal and perhaps somewhat greater amount was found. Mr. Wilson has reported for withdrawal about sixty reservoir sites of a thousand acre feet capacity or more, of which twenty-seven have each a probable capacity exceeding 9,000 acre-feet, eleven exceeding 45,000 acre-feet, seven exceeding 90,000 acre-feet, and four exceeding 200,000 acre-feet. The first rough estimate of capacity of all those thus far reconnoitered is not far from 4,000,000 acre-feet. Doubtless many others remain to be discovered as Mr. Wilson's examination covered less than one-third of the State.

ARKANSAS DIVISION.

Mr. Bodfish, who was assigned to the engineering survey of this river basin, did not take the field until about the middle of June, and his work commenced about the close of the fiscal year. The reasons for selecting this basin for special surveys were as follows:

While irrigation has made great progress in the valley of the South Platte it has been comparatively backward in the Arkansas Valley, which seems to offer as much advantage. The river, emerging from the mountains at Canyon City, flows due eastward out into the great plains. These plains are of such vast extent and so productive when watered, and their situation is so favorable in all respects, that it seemed as if some special effort should be made to devise a plan for irrigating a portion of them. The Arkansas is a decidedly spasmodic river near the mountains, carrying a large body of water in flood time, and shrinking to a small stream of about 250 to 500 second feet during the summer and autumn. If any considerable portion of its floods could be stored up, and let out upon the

plains during the irrigating season, a large body of extremely valuable land could be redeemed. The river, however, runs for a long distance in a depressed trough, and as a general rule, would require a long diversion line. In view of the great value of irrigated land in this part of Colorado, this would be no obstacle if the end in view were well secured. It was believed that there were several localities at which the diversion could be made with advantage, provided the amount of available water was sufficient to justify the undertaking. The water supply, in a great measure, turned upon the possibilities of storage.

It was currently believed that these possibilities were large. The localities in which it was supposed that reservoir sites could be found, and where many were asserted to occur, may be classified into three groups: First, those in the high mountain valleys and parks near the sources of the streams; second, those in the foot-hills, or "hog-backs" as they are termed, and third, those out upon the great plains.

In the mountainous portions of Colorado lakes occasionally occur, and when their outlets have a topography suitable for dam construction they may make good reservoirs, and a few of these are well known in the upper tributaries of the Arkansas. In many of these valleys lakes with flat bottoms of grassy or swampy land are also found, and these may also be turned into reservoirs whenever it is practicable to dam their outlets. These meadows, as they are termed, sometimes occur in the mountains. Being at a high altitude and near the melting snows, they are supplied with little loss, and the evaporation from the surface of such a reservoir is comparatively small by reason of the lower temperature and greater humidity of the situation.

It was further believed that in the foot-hills numerous sites might be found into which the water might be diverted from the river during the spring floods and taken out during the irrigating season. The peculiar construction of the hog-backs along the eastern front of the Rockies in Colorado might seem, at first, favorable to the occurrence of long, narrow valleys parallel to the trend of the range.

Much greater hope, however, was entertained of the possibility of storing large bodies of water in natural depressions in the plains. A considerable number of these were known to exist, some of them being of great magnitude and capable of holding large bodies of water. The engineering difficulties would be the length of canals required to take the floods of the river and carry them to these places, and to take the water out after it was once gotten in. Long lines of canal, however, when not prohibited by the expense, are objectionable by reason of the loss of water by evaporation and leakage.

The problem laid out for Mr. Bodfish in this valley was to ascertain, first, the possibilities of storage; second, the character of the work which would be required to divert the waters of the river either

for direct irrigation or for any possible reservoirs on the plains. There was still another question which seemed worthy of investigation. The ground in the valleys of the South Platte and in the Arkansas is favorable to the return of water to the stream bed by underground filtration. The percentage of irrigating water used in the South Platte which finds its way back to the river bed is known to be quite large; indeed, experiments recently made on or near the Cache la Poudre River indicate that it is even larger than was supposed. The ground in the Arkansas Valley near the mountains is apparently identical in this respect, and thus the possibility of using water over again becomes a question of importance. It is especially so in these two valleys in view of the fact that the lands in western Kansas and Nebraska require irrigation as much as those of Colorado, and the question is likely to arise at any time as to the respective demands of the two States upon the resources of the same rivers.

While this report is in preparation, Mr. Bodfish's parties are still in the field. Until the surveys are worked out in the office it is impracticable to give the precise results. Some general statements, subject to qualification when the office work shall have been completed, may be mentioned. A very thorough examination has been made in the region about the Tennessee Fork of the Arkansas. One large reservoir is the Twin Lakes, which are admirably adapted to the purpose. At a very moderate expense a dam can be constructed at the outlet which will create a holding capacity of 75,000 acre-feet. There is reason to believe, however, that this capacity is beyond the water supply to fill it. The entire water-shed which drains into the Twin Lakes is about 103 square miles, and it would be unsafe to estimate the run off at more than one foot over the entire area. Even this amount can not be relied upon with certainty, though it is slightly exceeded as shown by careful measurement in the drainage basin of the Cache la Poudre. On the whole it may be hoped that about 60,000 acre-feet of water will be available for catchment in the Twin Lakes. A second reservoir has been discovered in the neighborhood of the Twin Lakes in what is termed Hayden Valley or Park. Owing to the slope of its bottom it will require a high dam, say 110 feet, in order to fully develop its holding capacity. Two railroads which traverse it lengthwise will have to be relocated at considerable expense. Its holding capacity with a 110-foot dam would be about 60,000 acre-feet and its water-shed is somewhat larger than that of Twin Lakes. This would be a much more expensive work, not only by reason of the larger dam, but by the cost of removing the railroads. Still, at no very distant day the value of water will be great enough to justify it. Several small reservoirs on the Tennessee Fork have also been discovered, but they will not add largely to the total catchment. Surveys have been made of these reservoirs to determine their capacities and also of the dam

sites with sufficient details to enable estimates to be made of costs of construction and relocation of railroads.

All of the northern forks of the Arkansas River have been carefully examined for reservoir sites, both in the mountains and in the foot-hills or hog-backs. With the foregoing exceptions nothing more than some doubtful cases have been found. The southern forks remain to be examined, but no great hopes are entertained of better success in those quarters, unless possibly in the Wet Mountain Valley.

Search has also been made on the plains for available sites, but none have so far been found which promise any satisfactory results. There are several large basins, but in every case so far examined some fatal objection arises. It would be possible to fill some (at least partially) by means of long diversion lines, but there is no practical way of getting the water out again. Others are disproportionately large in comparison with the quantity of water which could be gotten into them. The water sheet so formed would be so thin that the great bulk of it would evaporate. Still others are too far away from any source of supply. The search, however, is not yet complete and has hitherto been made chiefly north of the Arkansas River. The topography of the south side is somewhat different and may yield more encouragement.

The results, then, so far obtained in respect to storage here are not large. The reservoirs on the Tennessee are the only definite additions to the available water supply, and they are of importance. Otherwise the prospects are not, at present, very extensive, but until an examination of the entire basin has been completed in a thorough and careful manner it would be premature to venture any confident or final opinion. The addition which may be made to the available supply of the Arkansas by the few reservoirs already found would be sufficient to double and perhaps to nearly treble it at the time when the water is most needed. The irrigation season in this part of Colorado lasts, roughly speaking, about 150 days or nearly five months. During this season the flood time occurs in which the river carries more water than is likely to be used. In the flood time the reservoirs would naturally be shut. It may be estimated that they would be called upon to deliver water for about 110 days in varying quantities, sufficient to make good the deficiency of the river. This deficiency varies, of course, within wide limits. We may estimate that the reservoirs would be called on to deliver an amount equal to the average deficiency of about 82 days. Allowing 120,000 acre feet as the net storage, the mean delivery for 82 days would be 1,460 acre feet per day. This is equivalent to a flow of 725 cubic feet per second. The mean flow of the Arkansas outside of the flood season and during the remainder of the irrigating season may be taken in an average year as about 425 feet per second. With the reservoirs

it would be necessary to deduct about 100 second feet to avoid reckoning twice over the amount captured in the reservoirs during the summer flow. Thus about 1,050 cubic feet per second might be maintained throughout the irrigating season by the use of these reservoirs as against 425 feet per second mean flow during the low stages with the river in its present condition. The reservoirs furthermore would give the incomparable advantage of enabling the distribution of water throughout the irrigating season according to the varying demand for it.

Mr. Bodfish has also made surveys of diversion lines along the Arkansas below Garden City, but they have not yet been worked out in this office.

The work in the Arkansas basin has been extensive and varied. The water supply furnished by the Arkansas River after the flood season is over is comparatively small. During the past season it ranged from 250 to 350 cubic feet per second, augmented occasionally by spasmodic floods. The amount of land in the Arkansas basin which could be reached by canals and irrigated with good effect if water were abundant is, we may say, indefinitely great. It was hoped that means might be found for greatly augmenting its supply by reason of the very large and high mountain regions in which its various tributaries take their rise. A large amount of reconnaissance work was performed for the purpose of ascertaining what promising sites for reservoirs might exist, and if any very promising ones were found it was determined to make surveys of them. A systematic search was instituted in all small creeks and tributaries which feed the Arkansas River above Canyon City and in its vicinity, each valley and branch being visited in turn by a competent engineer. Some success attended this investigation and we are in a position to say that the amount of water furnished by this river during the dry season can be very considerably increased by storage reservoirs, which can be constructed at a remunerative cost. But on the other hand the amount of storage capacity thus far found is considerably less than was hoped, and not at all commensurate with the wants of the immense areas of good, smooth, fertile lands spreading out upon the great plains immediately east of the front range of the Rockies.

The most important reservoir sites thus far discovered are upon the Tennessee Fork of the Arkansas above Leadville, of which the largest and best is at Twin Lakes. A careful survey has been made of this basin and of its dam site. A dam at no point exceeding 35 feet in height, with some excavation back of it to enlarge and deepen the outlet, will give a storage of about 100,000 acre-feet. These lakes have a water-shed whose area is 103 square miles, and it is estimated that this water-shed will have a run of probably not much exceeding fifty or sixty thousand acre-feet in an average season, but the available catchment can be very considerably increased by a

supplementary work, which will be spoken of presently. A little further up the Tennessee Fork is a second basin which could be converted into a reservoir of large capacity, but the expense of doing so would be very large, probably $1,000,000 or thereabout. It would require a dam 120 feet in height and five or six hundred feet long on top. It would, moreover, require the relocation of two railroads, the Colorado Midland and the Denver and Rio Grande, which run through the floor of the basin. And this relocation would be expensive and more or less detrimental to the railways. It has, however, been found practicable to tap the Tennessee Fork near the upper end of this reservoir, and by means of a canal carry its water around a mountain spur which separates the basin from that of Twin Lakes, and thus divert its waters into the Twin Lakes basin. The length of this canal would have to be about 12 miles and would involve some heavy work. By adding this water supply to that which is furnished by the water-shed of Twin Lakes it is believed that fully 100,000 acre-feet of water could be secured at a remunerative cost. A few other small basins have been discovered and surveyed in the Tennessee Park near Leadville and vicinity, and their united storage would probably be 40,000 acre-feet. The office work upon these reservoirs is not yet complete, but when it is completed we shall be in a position to state in full, detailed projects for storing water and all essential information concerning the nature of the dam sites, and to furnish the necessary data for approximate estimates of cost of construction.

RIO GRANDE DIVISION.

The Rio Grande is usually esteemed one of the larger rivers in the West. In flood time it usually carries a large volume of water, but at other stages the flow is small. During the last summer the river below Albuquerque was dry for nearly two months. This is no doubt due in part to the diversion of all the water in its upper portion into the San Luis Valley, the water supplied by lower affluents being insufficient to carry the stream much below Albuquerque. Before irrigation was inaugurated in the San Luis Valley the river always shrunk to a small volume in summer at El Paso, and in some years was dry at that place for a few weeks. There is, however, an unmistakable effect upon the lower courses by the diversion of the higher ones.

The greater portion of the course of this river in New Mexico lies between rocky canyons. Its trough deepens in the lower part of the San Luis Valley, and does not widen to any important extent till it opens in the Española Valley, about 20 miles north of Santa Fé. This valley is about 20 miles in length and 4 or 5 in width. It is well situated for irrigation, and has long been cultivated by the Mexican residents and Pueblo Indians in their usual fashion. Some of the tributaries, notably the Taos, and especially the Chama, have

some agriculture, and might have much more. At the foot of the Española Valley the river again enters the canyon and emerges near Bernalillo. Here the valley widens out and contains for a distance of nearly a hundred miles a border of land, which might be irrigated if water could be brought upon it. At San Marcial the river once more enters a long rocky gorge leading along the western borders of the Jornado del Muerto. At Fort Selden it enters the Mesilla Valley, which is nearly 60 miles in length and of considerable width. At the southern end of this valley is El Paso, where the river breaks through a low rocky pass 3 miles in length, and enters a wide valley, which extends as far as Fort Hancock, 60 miles below El Paso.

From Bernalillo to Fort Hancock there is but little agriculture, and such as exists is practiced mostly by the Mexican residents and is of a primitive kind. In fact, no other is practicable without extensive and costly works to control the water. All this portion of the Rio Grande is in the highest degree spasmodic, with immense floods during a few weeks of the year and a small stream during the remainder of it. Under such circumstances the extent of possible agriculture is measured by the smaller—almost by the smallest flow. The possibility of utilizing a goodly portion of the flood waters is a problem worthy of the most earnest consideration. No climate could be more advantageous for profitable agriculture. To arrest so large a body of water as the Rio Grande in flood would require very large reservoirs, and to utilize them would also require a very favorable location of their basins. The belief has been held for some years by residents of El Paso that both of these conditions are fulfilled at the lower part of the Mesilla Valley. At the pass near El Paso, where the river traverses a narrow gorge, it seems as if it might be possible to build, at moderate cost, a reservoir which would hold back the whole of the flood waters of the river. Immediately below the pass are the wide bottom lands, where 300,000 acres could be watered and where the climate is sub-tropical. A matter of special importance attaches to this project, for it involves international interests. Beginning at El Paso the Rio Grande is the Mexican boundary, and the land which such a reservoir would command is about half in Texas and half in Mexico. For more than a century the Mexicans have used the water for irrigation, and their interests are as deeply concerned as our own. The impoverishment of the river by the extensive diversions in Colorado have wrought great injury to the Mexican farms, and if priority of right can be claimed as between citizens of adjoining countries the priority is certainly vested in the citizens of Mexico. Although the value of property involved is of no great amount, the principle involved is a highly important one. Furthermore, serious questions have arisen, growing out of the shifting of the bed of the river, whose channel is made by treaty the boundary

of the two nations, and these have been the subject of much complaint by the Government and people of Texas and of diplomatic discussion with the Government of Mexico. It is apparent that if the floods of the Rio Grande were caught above the pass these shiftings of the channel would be wholly prevented, for the changes are incident to the uncontrolled action of the floods, which would be wholly stopped unless they were so copious as to more than fill the reservoir, and even then they would be so mitigated as to be harmless.

The project of a dam at El Paso has for some years been a subject of interest to Major Anson Mills, of the Army, who, from a disinterested standpoint, has given it a great deal of study. Being stationed at Fort Bliss on military duty, he was ordered by the Secretary of War to render such assistance as was in his power to the Geological Survey, and make an examination of the project. Mr. W. W. Follett was sent to El Paso to make the necessary surveys. His work did not begin until after the fiscal year. In July, August, and September the work was completed, and his report was made in October.

Mr. Follett finds it practicable to construct a masonry dam at the pass 65 feet above the river bottom, with an adequate waste-weir, which will create a lake 14½ miles in length and 4 miles maximum width, with a surface of about 26,000 acres, and an average depth of 23.6 feet. Its cubical contents will be 537,000 acre-feet. There were two sites about 1¾ miles apart, which presented themselves in the pass for making a dam. The upper one, giving a considerably shorter length of dam, was chosen for survey and estimate. Some difficulties not of an insurmountable nature were peculiar to both places. The river bed is occupied with quicksand in both localities, but it is from 30 to 50 feet in depth at the upper and narrower one, and only 8 to 22 feet in depth at the lower one. At the lower site one end of the dam would be in Mexican territory; at the upper site both ends would be in United States territory. In both of them two railroads—the Southern Pacific and the Atchison, Topeka and Santa Fé—would require to be relocated, at great expense; but at the upper site the relocated grades of the Atchison and Topeka could be made to conform readily to the ruling gradient of that division of the road, while at the lower one it could not be without changing their depot and terminal facilities in El Paso. On the other hand, the lower site would compel the Southern Pacific road to enter Mexican territory, in which case the cost of relocation would be great. The upper site would afford facilities for building the dam higher if it should be called for, while in the lower one this would be far more difficult. The dam at the upper site would be of much more expensive construction than at the lower one on account of the greater depth of the quicksand. In either case, if the construction of a dam were all, the lower site would, on the whole, be preferable, but the railroad complications appear to incline the balance in favor of the upper one. The question as be-

tween the two, however, may be regarded as an open one, worthy of still further consideration.

Mr. Follett's surveys and estimates were made in detail at the upper site. The uncertain element of cost is the keeping open of the excavation in quicksand. The Poetch process of freezing the wet sand by pipes and refrigerating machinery has in many cases proved highly effective, but its application has hitherto been, so far as known, upon a smaller scale than would be necessary here, and under circumstances of a somewhat different nature. It would, however, naturally receive very careful consideration in this connection. Mr. Follett's estimate, however, is based upon the use of crib work and wooden caissons. His estimate of the cost of the dam is a little over $300,000.

The cost of removing the railroads is estimated by him at $205,000 for the Southern Pacific, and $385,000 for the Atchison, Topeka and Santa Fé. Both of these relocations would involve a considerable amount of heavy rock work. Some land in the Mesilla Valley which would be overflowed by the reservoir would have to be condemned, but land now occupied in the lower part of the valley is of small value. He estimates the cost of the site at about $69,000. His total estimate for the entire work, including 10 per cent. for administration and incidentals, is $1,059,695.

This cost is very moderate in comparison with the value of the stored water. An acre-foot of water in such a locality may be estimated as worth at a minimum $1.50 per annum, and this valuation should increase with the lapse of time. What proportion of the stored water would be available for irrigation would depend upon the nature and distribution of the canal lines below and the amount of land which they could be made to command. At least 200,000 acre-feet would be availabe for high-line canals. To secure such a body of stored water, an expenditure of considerably more than $2,000,000 would probably be ultimately justified and would be remunerative.

A question of grave importance arises in connection with the sediment which the Rio Grande carries. Like all spasmodic rivers in dry climates, the amount of it in flood time is very large.

Some investigation has been made on this point with a view of ascertaining how long it would require the river to deposit sediment enough in the reservoir to seriously impair its utility. The sediment of the river during the last high-water stage was frequently sampled, and was found to range from about one-fourth to one-half of 1 per cent. of the volume of the flow, averaging by 118 samples .345 of 1 per cent. This represents only the suspended sediments, and does not include the grosser material swept along on the bottom, whose quantity has not yet been estimated. On the whole it seems probable that a life of more than one hundred years before the reservoir is seriously impaired by the sediment may be counted upon.

This might be greatly prolonged by the use of settling reservoirs along the course of the river through the Jornado del Muerto. There are several large basins, termed locally *rincons*, in that portion of the river, which could be used for that purpose, a settling basin being constructed whenever an older one is filled up.

CALIFORNIA DIVISION.

In this State irrigation has made greater advances than in any other. The chief developments however have been in the southern half of the State. In the northern half the necessity of irrigation has not until within the last ten years been felt to be so absolute as it is in the southern half. In most seasons some of the grosser staple crops were found to mature in the Sacramento Valley without irrigation. But with the increase of fruit culture it became practically necessary. The large affluents of the Sacramento, the Feather, and Yuba rivers, as well as the Sacramento itself, are not as yet fully utilized. In the San Joaquin Valley, on the other hand, the rivers in their natural condition have been wholly diverted during the lower stages. Irrigation in that valley has from the beginning of settlement been absolutely indispensable. There is a marked difference between the east and the west sides of both valleys in respect to climate and a still more striking one in respect to water supply. The west side is the more arid in climate, and has only a few spasmodic streams which are dry during the greater part, if not the whole, of the irrigating season. The eastern side is more humid and has many considerable streams descending from the Sierra Nevada. These, however, have been found insufficient in the San Joaquin Valley to irrigate more than a rather small fraction of the land. The necessity for more water here is a pressing one, and the only method of obtaining it is by storage. The problems, however, on opposite sides of the great valley of California are totally distinct. On the eastern side the reservoirs would be only supplementary, and in most cases subsidiary to the rivers. On the western side they would be the sole reliance. In the Sacramento Valley, moreover, the reservoir problem, on the eastern side at least, is a question rather of future than of present necessity, while on both sides of the San Joaquin it is an instant one.

In beginning the work in this State Mr. Hall was instructed to make an examination of the central part of the Sierra Nevada around the headwaters of the Stanislaus, Tuolumne, and Merced Rivers for the purpose of locating reservoir sites. It was expected that this search would be continued as the funds appropriated might permit as far south as the headwaters of the Kern River. North of the Mokelumne or Cosumnes River the Sierra Nevada range has the general configuration of a slightly inclined plateau, sloping westward,

with deeply incised valleys and many irregularities, but also with many broad and flat table-lands between. In this portion many places known to be suitable for reservoirs exist and some of them have already been utilized to store water for hydraulic mining. They drain chiefly into the Yuba and American Rivers and it was not deemed pressing at the present stage of the inquiry to investigate them. The country around the headwaters of the Stanislaus and Tuolumne is much more rugged and affords fewer tracts in which reservoirs may be looked for. Around the sources of the Merced it is equally rugged. South of this river the Sierra platform becomes much less irregular and the possible or hopeful localities for reservoir sites are more numerous and extensive.

Mr. Hall's field work was not started until July. He placed a party in the field around the headwaters of the Stanislaus under the immediate charge of Mr. Luther P. Wagoner, who successively explored this tract and those around the sources of the Tuolumne and Merced. The results of this work are not yet to hand and have not been completed in the office. But, in a general way, it may be said that a few sites have been located as capable of being converted into reservoirs and a larger number, which belong to the doubtful class, whose capabilities can not be decided upon until after a thorough investigation. It is to be noted, however, that this region is the least hopeful of any portion of the Sierra, and more gratifying results may be anticipated when the survey shall have reached the headwaters of San Joaquin, King's, and Kern Rivers. Indeed, one admirable reservoir site of grand proportions is known to exist near the sources of Kern River.

In the hope of discovering something which might be of prospective value to the western side of the valley Mr. Hall was instructed to make an examination of Clear Lake in the coast range. This large sheet of water must receive a very considerable inflow, but during the year the outflow is small. The difference is accounted for by evaporation. There are numerous lakes throughout the West which present no difficulties of an engineering character which could prevent turning them into great reservoirs. They also receive large rivers. But the broad surfaces they offer to evaporation render them of inferior value for this purpose. In some cases it is possible to contract the surface, still leaving sufficient capacity to store the inflow, thus diminishing the loss. In other cases this is impracticable. Clear Lake was regarded as an example which was worthy of special investigation. If it could be made to yield any considerably increased outflow the water would have exceptionally high value. The lands which it might irrigate are among the most valuable in the country for fruit culture. A second party was therefore organized, in charge of Mr. C. G. Rockwood, to make a thorough survey of the lake and its outlet. This survey was completed early in Octo-

ber and the field notes are now being worked up in the office. At the present time the results of the survey are not to hand.

In the northern part of the State, east of the Sierras, in Modoc and Lassen Counties, there is a large amount of fine land needing water. Although the precipitation upon the mountains is quite large, and is not inconsiderable even upon the adjoining lowlands, there are very few streams which are available. The country, on the whole, is favorable to the occurrence of reservoir sites. It was therefore decided to make a reconnaissance in search of them. Two men were sent upon this errand in the month of July and found several sites, two of them of large capacity.

Further work is contemplated during the winter in the southern part of the State, but its details are not yet decided upon.

LAHONTAN DIVISION IN NEVADA.

It was believed that in the State of Nevada better results might be hoped for in the basins of the Truckee and Carson Rivers than elsewhere. These streams head immediately under or upon the crest of the Sierra and where the snow-fall is heavy and where the water passes through lakes, or basins which may have once been lakes but are now empty and can be converted into lakes again. The Truckee drainage is exceptionally favorable for storage. The main fork of the river issues from Lake Tahoe and a dam could be built across the outlet at an insignificant cost. Tahoe, however, is one of those lakes which is too large for a good reservoir. Its surface is about 190 square miles in extent while its entire water-shed does not exceed 500 square miles. Its inflow must be quite abundant, however, as the feeders rise under the very eaves of the Sierra Nevada when the precipitation is large. But the great surface exposed to evaporation returns much the larger portion of the inflow to the atmosphere. Nor can this surface be diminished, for Tahoe is a very deep lake, in fact one of the deepest in the world, and the slopes of its basin descend into the depths with great abruptness. Even if it were possible public sentiment would justly regard such a change as vandalism, destroying or marring one of the most beautiful sheets of water on the globe. No degree of utility for irrigation purposes would compensate such an injury. A single foot of water, however, over this large surface would suffice to irrigate 50,000 acres of land, and the question arises whether such a supply may not be obtained. The question is a meterologic rather than an engineering one. All the construction which could be of any avail would cost less than $5,000. The best method of reaching a solution may be prescribed at once. It is to build a dam and try it. The cost would be trifling and the result incontrovertible. Even if it proved a failure the advantage of setting the question at rest would be worth far more than the cost.

Immediately above the town of Truckee is Donner Lake, a beautiful sheet of water about 2½ miles long and half a mile wide, with a surface of about 900 acres. It is well adapted for a moderate-sized reservoir. Its immediate watershed is only 13 square miles. But just below its outlet a second valley—the Coldstream—opens into its lower basin, with 15 or 16 square miles of watershed. Both valleys are immediately under the crest of the Sierra and receive a large annual precipitation, Its precise average is unknown, but is conjectured to be nearly 33 inches per annum. The run-off is also unknown, and an estimate would at present be hazardous. But if like situations and conditions may be used as the basis of a preliminary estimate, an annual run-off of a foot over the entire area may be a moderate one, giving about 18,000 acre-feet available for storage.

A few miles further north lies Independence Lake, of about the same size as Donner Lake. Its available catchment is uncertain, but the indications now are that it will be equal to that of Donner Lake, if not larger, as a stream of about 35 feet per second was flowing out of it late in August. Still further north is W( )er Lake. This is less than half the size of either of the other two and its watershed is small; but it is at the summit of the Sierra and its tribute must be considerable. Both Weber and Independence Lakes drain through the Little Truckee, which enters the main river near the village of Boca. There is still a fourth basin between Donner and Independence which is probably capable of being converted into a good reservoir, but it contains no lakes. The indications now are that 50,000 or 60,000 acre feet of water may be stored in the four basins at a reasonable cost. To this may be added the unknown amount obtainable from Tahoe.

The Carson River is a much larger stream than the Truckee, carrying at rather low stages not far from 1,000 cubic feet per second. There is the possibility of storage near its sources, but it will be less in amount and more expensive to attain than in the Truckee Basin. At the head of the west fork of the river in Hope Valley there is a considerable basin which might be converted into a reservoir, but the dam would have to be large and costly. The watershed is ample and being situated upon the summit of the Sierra platform, a very large supply of water would be available for catchment. A second site of smaller proportions occurs between the east and west forks in Long Valley. It might be filled by a diversion from the east fork, but this would involve a tunnel or deep rock cut. Moreover, there is no good material of which to build it in the immediate neighborhood and the abutments for the dam are not satisfactory. It would be a somewhat costly undertaking. Another possible site is near Markleeville, on the east fork, but, as no survey has been made of it, its capabilities are unknown.

Mr. Lyman Bridges, who was assigned to the charge of this divis-

ion, took the field in June, and made surveys of Donner, Independence, and Weber Lakes, in the Truckee Basin, and of Hope Valley and Long Valley, in the Carson Basin. The results of this survey are yet to be worked out in the office, and it is not practicable at present to give more definite accounts of them than those already stated. He also examined the trough of the Truckee, near Wadsworth, with a view to ascertaining the best methods of taking water from the river and carrying it to the lands lying southeast of that town, which are well situated for receiving it and of more than sufficient extent to utilize it.

SNAKE RIVER DIVISION.

The Snake is one of the large rivers of the West, carrying at the lowest stages more than 3,000 second feet of water. Its sources in Yellowstone Park and in the Teton and Wind River ranges are regions of large precipitation, which yield many perpetual streams. Emerging from the mountains the Snake flows out into an immense plain 250 miles in length and from 50 to 100 miles in width. A large portion of this plain has been overflowed, in comparatively recent geological times, by extravasations of basaltic lava, much of which is still an expanse of black barren rock, while some of it is imperfectly buried in drifted sand and soil. But there are also some millions of acres of land of excellent quality and as favorably situated for an extensive irrigation as any in the West. Indeed, it may be said that the eastern portion of the Snake River plains offers about the best opportunity for a splendid irrigation development of any portion of the West whose capabilities are at present understood. Settlement, however, has until within the last two or three years, almost wholly avoided it. The reason is not far to seek. There is little opportunity for the pioneer stage of development. This stage requires small streams which can be attacked by the resources of a few settlers without capital. Outside of the mountains the Snake has exceedingly few small tributaries. Whatever is done must require the resources of more or less capital. With very slight qualification the development must in the ordinary course begin at the second stage, that of multiple ditches. Until very recently there has been no sufficient demand for land to cause the development to leap over the first stage and begin with the second. It has, however, begun now, and for two years has been proceeding with a rapidity that may well be regarded as formidable.

This great river and the large extent of land adjoining it capable of being irrigated by its waters, offered a problem of the highest interest, and it was determined to make a thorough examination of their capabilities. Mr. A. D. Foote was assigned to this division and began his field work in June. A field party was equipped in charge of assistant A. W. Wiley, and at once began the survey of a

high-line canal route, taking water at Eagle Rock on the Utah and Northern Railroad and extending southward to Pocatello. At Eagle Rock the banks of the river are very low and a natural dam site is found. There is practically no diversion-line necessary. The canal can leave the river bed at once, coursing directly for the foot-hills to the southeastward, and having good agricultural land under it almost from the very beginning. It would command all the land between the foot-hills of the Snake River range and the river; and more favorably situated or better land can not be found. There is hardly an acre of waste ground in the entire tract of more than 200,000 acres. The examination of the lands on the right bank was postponed until the early spring owing to the total absence of water, which may be looked for only after the early rains.

While Mr. Wiley was surveying the canal route, Mr. Foote himself undertook a reconnoissance of the main fork of the river in search of reservoir sites. The result of his search was most gratifying. At the head of the main fork of the Snake are Shoshone and Lewis Lakes, both of which might make reservoirs, but only of very limited utility. Much better resources were found. At Jackson's Lake, between the Teton and Wind River ranges, it is possible to construct, at relatively small cost, a reservoir which will hold a far greater body of water than the entire annual flow of the river above the lake's outlet. The present area of the lake is not far from 40 square miles, while its water-shed is between 750 and 800 square miles. The precipitation over this area is, for the Western country, a maximum. In estimating the resources of grand reservoirs it is to be borne in mind that their utility is in most cases greatly impaired by loss from evaporation. But when the ratio of inflow to surface exposed is large, the perc ntage of loss is greatly reduced and the value of the reservoir is vastly increased. This is the case with Jackson's Lake. The indications now are that, after a reasonable allowance for evaporation, an available output of stored water may be obtained from Jackson's Lake of at least 500,000 acre-feet, and possibly much more.

Farther down the fork at Swan Valley is another reservoir site of the grandest proportions, with a narrow outlet where a dam can be constructed at moderate cost. A little above it is another basin of somewhat larger proportions, but in a hasty reconnoissance it was impracticable to form a confident opinion upon the dam site.

On the Falls River fork of the Snake, which is the second branch in respect to size, a reservoir site has been discovered which is of almost indefinite capacity. The available catchment will be insufficient to fill it. An apparently good dam site exists.

All these basins remain to be surveyed with a view of ascertaining more definitely their capacities, available catchments, and cost of construction. But enough is known to warrant the statement that the possibil ties of storage are vast, far exceeding that of any other

known river in the West, and that the cost, though absolutely considerable, will be small relatively to the value of the stored water. The larger portion of the upper tributaries of the Snake remains to be reconnoitered for reservoir sites. Many others are reported and the topography of the country is favorable to their occurrence.

Mr. Foote has also made an examination of the question of taking out the water of the Snake at American Falls, on the south side, with a view of reaching some good lands below that place. The scheme was found to be impracticable by reason of prohibitory cost.

Very respectfully,

C. E. DUTTON,
Captain, etc.

EXPENDITURES.

Classification of expenditures of $100,000 *for irrigation*, 1889.

A. Services		$40,628.37
B. Traveling expenses		9,959.97
C. Transportation of property		1,705.72
D. Field subsistence		6,333.57
E. Field supplies and expenses		8,940.53
F. Field material		17,756.74
G. Instruments		11,420.12
K. Books and maps		28.60
L. Stationery and drawing material		727.08
O. Office furniture		97.25
P. Office supplies and repairs		100.85
Q. Storage		105.00
R. Correspondence		264.97
Bonded railroad accounts settled at Treasury, viz:		
Transportation of assistants	$1,280.35	
Freight	519.34	
		1,799.69
Unexpended balance		131.54
Total		100,000.00

Abstract of disbursements made by Jno. D. McChesney, chief disbursing clerk, U. S. Geological Survey, during the second quarter of 1889.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1888.				
Oct. 23	83	C. E. Dutton	Traveling expenses	$15.70
24	88	S. J. Haislett	Field expenses	32.00
31	123	Pay-roll of employés	Services, October, 1888	188.22
31	128	do	do	37.10
Nov. 2	138	do	do	158.86
2	140	G. E. Verrill	Traveling expenses	39.15
2	141	Josiah Pierce, jr	do	39.25
2	142	H. M. Wilson	do	16.25
2	143	do	do	12.75
5	146	Robert Robertson	do	19.51
6	152	Baltimore and Ohio R. R	Transportation of assistants	570.35
14	174	Sparks Bros	18 horses	2,358.00
14	175	Asken Bros	26 horse blankets	105.00
15	178	Quartermaster's Department U. S. Army.	Tents	302.91

Abstracts of disbursements made by Jno. D. McChesney, etc.—Continued.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1888.				
Nov. 20	188	E. R. Rail	Field material	$616.11
20	189	D. G. Kitzmeyer	....do	441.65
20	190	D. Kaiser	Subsistence supplies	67.05
20	191	G. T. Davis	....do	109.05
20	194	H. M. Wilson	Miscellaneous field supplies	96.05
20	195	....do	Field material	387.00
20	196	....do	Traveling expenses	20.00
20	197	Pay-roll of employés	Services, October, 1888	20.79
22	203	R. S. Tarr	Traveling expenses	17.90
22	204	Geo. T. Quinby	....do	17.35
22	210	Henry J. Green	Instruments and repairs	217.35
22	211	Pennsylvania R. R.	Transportation of assistants	46.65
23	217	J. H. Boring	Traveling expenses	9.25
23	218	....do	....do	24.33
23	219	G. T. Davis	Field subsistence, etc	52.97
23	220	Josiah Pierce, jr	Field expenses	24.79
23	221	W. D. Torreyson	Field material	134.00
23	222	G. E. Verrill	Field expenses, etc	32.90
24	223	H. M. Wilson	....do	185.08
30	244	R. S. Swift	18 mules	2,421.00
30	259	Pay-roll of employés	Salary, November, 1888	110.00
30	262	W. D. Castle	Supplies	14.00
30	263	Robert Robertson	Services, October 30 to 31, 1888	3.87
Dec. 6	291	John Schultzback	Instruments	83.00
10	305	Fred A. Schmidt	Topographic supplies	16.50
18	340	United States Express Co	Freight charges	.25
20	357	C. H. Pond	Irrigation supplies	14.00
27	370	Western Union Telegraph Co	Telegrams	34.32
27	371	Library Bureau	Letter-file case	77.00
27	378	S. J. Haislett	Tents	40.00
31	421	Pay-roll of employés	Services, December, 1888	156.13
31	430	Atchison, Topeka and Santa Fé R. R.	Transportation of assistants	6.65
		Total		9,392.04

Abstract of disbursements made by Mark B. Kerr, disbursing agent, U. S. Geological Survey, during the second quarter of 1889.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1888.				
Oct. 13	26	H. M. Wilson	Field expenses	$26.25
13	50	A. F. Dunnington	....do	49.50
13	51	R. H. McKee	....do	57.81
13	52	Dan D. Calkins	....do	8.50
15	54	Paul Holman	....do	1.40
16	57	A. F. Dunnington	....do	58.65
17	58	R. H. McKee	....do	60.19
17	59	....do	....do	30.77
18	60	Arthur P. Davis	....do	54.81
21	62	R. Henry Phillips	Traveling expenses	22.25
22	63	Dan D. Calkins	Field expenses	43.25
25	65	W. L. Tremble & Co	Forage	27.00
25	68	H. M. Wilson	Field expenses	116.86
27	69	F. G. Pratt & Co	Field subsistence	22.21
27	70	A. E. Laudenslager	....do	21.84
27	71	G. W. Bond & Co	Field supplies	10.45
27	72	Arthur P. Davis	Field expenses	49.35
27	73	A. F. Dunnington	....do	69.80
31	75	Paul Holman	Services, October, 1888	66.23
31	78	Pay-roll (McKee)	....do	265.25
31	80	H. M. Wilson	Field expenses	74.50
31	81	....do	Services, October, 1888	92.39
31	82	Pay-roll (Davis)	....do	753.59
Nov. 7	89	Pay-roll (Chapman)	....do	342.30
8	90	Frank Tweedy	Field expenses	35.76
8	91	Pay-roll (Tweedy)	Services, October, 1888	326.55
8	92	Pay-roll (Dunnington)	....do	236.44
8	94	Redick H. McKee	Field expenses	31.25
8	95	A. F. Dunnington	....do	44.55
8	98	J. Karker & Co	Field repairs, etc	19.50
8	99	A. E. Laudenslager	Field subsistence	86.43
8	100	Harry H. Hackett	Services, October 30, 1888	3.23

Abstract of disbursemente made by Mark B. Kerr, etc.—Continued.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1888.				
Oct. 8	102	Dan D. Calkins	Field expenses	$20.50
8	103	Arthur Bishoff	Field material	8.98
8	105	Reaser Bros	Field subsistence	143.28
8	106	W. H. McKenzie	Field supplies	38.15
8	107	Redick H. McKee	Field expenses	40.95
8	108	A. F. Dunnington	do	34.00
5	111	Mark B. Kerr	Services, October, 1888	141.82
13	112	A. F. Dunnington	Field expenses	29.90
15	116	Philip S. Levills	Traveling expenses	25.25
15	118	R. H. Chapman	Field expenses	4.50
15	119	Arthur P. Davis	do	85.15
15	120	Van Arsdell & Co	Forage	19.30
16	121	A. F. Dunnington	Field expenses	63.60
21	125	Sparks Bros	Forage	14.50
21	126	A. Holmes	Services, November 1 to 10, 1888	15.00
22	129	Redick H. McKee	Field expenses	42.00
22	130	Arthur P. Davis	do	57.20
28	131	A. H. Thompson	Traveling expenses	191.50
28	134	Josiah Pierce, jr	Field expenses	73.06
28	135	G. E. Verrill	do	67.17
28	136	H. M. Wilson	do	51.89
28	138	Redick H. McKee	do	78.25
30	140	Arthur P. Davis	Services, November, 1888	163.00
30	142	Redick H. McKee	Field expenses	21.00
30	143	Pay-roll (McKee)	Services, November, 1888	177.40
30	144	Frank Senn	do	6.67
30	145	Harry H. Hackett	do	50.00
30	146	J. H. Boring	Services, October, 1888	45.16
30	150	Pay-roll (Wilson)	Services, November, 1888	809.20
30	151	William L. Maxwell	Traveling expenses	6.00
30	152	Dan D. Calkins	do	33.75
30	153	William L. Maxwell	Services, October, 1888	20.32
30	155	Pay-roll (McKee)	Services, November, 1888	140.00
30	156	S. P. Johnson	Services, December, 1888	27.09
30	157	R. H. Chapman	Services, November, 1888	97.80
30	158	Alice M. Prouty	Services, December, 1888	5.16
Dec. 15	161	Pay-roll (Davis)	Services, November, 1888	220.00
15	162	Pay-roll (Douglas)	do	384.96
15	163	Frank Tweedy	Traveling expenses	115.20
15	164	H. M. Wilson	Field expenses	72.12
15	165	do	Field supplies	5.00
15	168	C. S. Swift	Services, November, 1888	39.00
15	169	Charles W. Friend	do	19.00
15	171	R. H. Chapman	Services, October, 1888	9.27
15	172	E. M. Douglas	Field expenses	44.54
15	176	Pay-roll (Davis)	Services, November, 1888	763.10
15	177	Mark B. Kerr	Field expenses	19.94
Nov. 30	179	do	Services, November, 1888	146.80
Dec. 15	180	Redick H. McKee	Field expenses	110.72
15	181	Harry A. Hackett	Services, December, 1888	4.84
15	183	José D. Martinez	Forage	12.00
15	187	H. M. Wilson	Field expenses	39.67
15	188	G. T. Davis	Field subsistence	99.14
15	189	A. F. Dunnington	Field expenses	2.50
15	190	do	Traveling expenses	129.75
15	191	H. M. Wilson	Field expenses	80.86
15	192	G. E. Verrill	do	36.00
15	193	Josiah Pierce, jr	do	51.53
15	194	William Bolander	do	95.15
15	195	A. F. Dunnington	do	40.31
17	199	Western Union Telegraph Company	Telegrams	14.85
17	201	do	do	9.22
17	205	Arthur P. Davis	Services, October, 1888	9.27
17	206	Paul Holman	Services, November, 1888	68.40
17	208	G. E. Verrill	Field expenses	32.35
17	209	A. H. Thompson	Traveling expenses	180.00
20	210	Henry Gannett	do	132.90
23	211	Josiah Pierce, jr	Field expenses	37.93
23	212	Arthur P. Davis	do	76.02
23	213	R. H. Chapman	do	32.20
23	214	Thomas Clement	Storage	12.50
23	215	W. S. Montgomery	Pasturage	67.00
23	216	C. S. Swift	Services, December 1 to 10, 1888	15.00
23	217	Mark B. Kerr	Services, December, 1888	151.60
31	224	R. H. Chapman	do	101.10
31	225	Paul Holman	Traveling expenses	122.00
31	233	Pay-roll (Kerr)	Services, December, 1888	460.30
		Total		10,021.40

Abstract of disbursements made by Anton Karl, disbursing agent, U. S. Geological Survey, during the second quarter of 1889.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1888.				
Oct. 17	1	J. C. McGuire	Traveling expenses	$19.50
16	2	Anton Karl	....do	19.00
17	3	Louis William Mohun	....do	19.25
16	4	W. H. Hyatt	Horse-shoeing	6.00
16	5	....do	Field material	125.75
16	6	....do	....do	405.00
16	7	....do	....do	254.50
19	8	F. Morgan	Services, October 17 and 18, 1888	5.00
22	9	Willard D. Johnson	Traveling expenses	24.25
22	10	William S. Post	....do	19.25
22	11	W. B. Corse	....do	18.50
22	12	Alexander C. Barclay	....do	45.35
22	13	Samuel A. Foot	....do	18.00
22	14	Perry Fuller	....do	18.00
22	15	W. C. Wertman	Services, October 22, 1888	1.75
22	16	Willard D. Johnson	Camp equipment	680.10
23	17	W. C. Furst	Subsistence	63.00
23	18	W. H. Hyatt	Transportation	25.00
24	19	A. E. Finn	Subsistence	6.60
24	20	Willard D. Johnson	Camp equipment	189.14
24	21	....do	Subsistence and camp equipment	188.87
27	22	John B. Karcher	....do	10.50
27	23	E. Weaver	Transportation	9.00
30	24	Robert A. Farmer	Traveling expenses	18.85
30	25	Pay-roll	October, 1888	487.68
30	26	....do	....do	101.59
30	27	J. W. Hays	Traveling expenses	21.10
30	28	W. H. Hyatt	Field material	242.75
Nov. 3	29	A. E. Finn	Subsistence	34.00
6	30	Willard D. Johnson	Camp equipment	390.93
7	31	D. C. Crawford	Subsistence	28.50
7	32	John T. Williams	Transportation	24.25
14	33	Willard D. Johnson	....do	382.00
15	34	A. E. Finn	Field material	5.00
15	35	Anton Karl	Field expenses	10.60
16	36	Willard D. Johnson	Camp equipment	162.98
16	37	Annie Campbell	Subsistence	30.50
12	38	John Taylor	Transportation	22.00
15	39	Anton Karl	Traveling expenses	8.50
19	40	Mrs. James Kennedy	Subsistence	28.12
19	41	J. B. McNeal	Transportation	23.25
19	42	John Burt	Subsistence and transportation	6.00
21	43	Clay Bell	Subsistence	22.00
23	44	S. A. Snyder	Transportation and field material	1.75
23	45	Anton Karl	Traveling expenses	6.25
26	46	....do	Telegrams	6.17
29	47	S. A. Snyder	Field expenses	8.25
29	48	F. Bradley	Expressage	1.70
28	49	H. S. Stansbury	Services, November 26, 1888	2.25
29	50	John Fisher	....do	2.50
29	51	Edward Elgenfritz	Subsistence	41.16
30	52	Pay-roll	November, 1888	150.00
30	53	Willard D. Johnson	Field material	99.26
30	54	....do	Subsistence	117.15
Dec. 1	55	Pay-roll	November, 1888	723.09
4	56	Charles P. Abdell	Traveling expenses	40.80
3	57	Noah Cann	Subsistence	14.70
3	58	S. Montrose	....do	9.00
7	59	John Boyd	....do	25.00
18	60	J. W. Dobbins	Traveling expenses	5.40
8	61	Willard D. Johnson	Subsistence and field material	221.01
7	62	E. Forster	....do	1.50
9	63	Noah Cann	Transportation	1.90
10	64	John Boyd	Subsistence	1.25
13	65	W. H. Lithgran	....do	21.00
14	66	H. F. Comstock	Expressage	1.00
13	67	J. S. Parker	Lodging and transportation	44.25
16	68	A. E. Finn	Subsistence	19.85
17	69	Edward Rollandet	Field material	5.00
17	70	Anton Karl	Traveling expenses	5,45
17	71	....do	....do	14.10
20	72	Clay Bell	Subsistence	12.00
24	73	Anton Karl	Telegrams and expressage	5.96
31	75	Pay-roll	December, 1888	833.20
31	76	Anton Karl	Traveling expenses	20.75
19	77	W. H. Hyatt	Transportation	68.50
29	78	J. C. McGuire	....do	52.31
		Total		6,805.37

Abstract of disbursements made by P. H. Christie, special disbursing agent, U. S. Geological Survey, during the second quarter of 1889.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1888.				
Nov. 30	1	Pay-roll	Services, November, 1888	$467.50
30	2	P. H. Christie	Services, November 16 to 30, 1888	73.37
Dec. 10	3	Geo. T. Quinby	Traveling expenses	28.05
10	4	Fred'k H. Newell	do	92.10
10	5	J. B. Williams	do	111.65
11	6	Palace Hotel	Subsistence	90.00
11	7	Gerard D. Koch	Field supplies	112.94
12	8	H. B. Cartwright	do	95.08
12	9	W. A. McKenzie	do	144.43
13	10	R. S. Tarr	Traveling expenses	42.82
13	11	P. H. Christie	do	157.15
14	12	Geo. T. Quinby	Field expenses	101.33
19	13	R. S. Tarr	do	13.95
19	14	Albina Lopez	Subsistence	24.37
19	15	F. H. Newell	Field expenses	35.60
20	16	C. E. Dutton	Traveling expenses	72.85
20	17	Philo. Rumsey	Subsistence	53.38
20	18	W. A. McKenzie	Field supplies	49.06
22	19	Gumsfeld, Lindheim & Co	do	21.47
22	20	Gerard D. Koch	do	30.32
22	21	W. A. McKenzie	do	52.75
22	22	H. B. Cartwright	do	168.72
26	23	Palace Hotel	Subsistence	37.00
31	24	Pay-roll, December, 1888	Services	825.62
31	25	George E. Curtis	Traveling expenses	18.78
31	26	Alfred C. Lane	do	90.60
31	27	P. H. Christie	Field expenses	94.52
31	28	Pay roll of employés	Services, December, 1888	97.57
31	29	F. H. Newell	Field expenses	46.93
31	30	George E. Curtis	Services, December 20 to 31, 1888	45.15
		Total		3,295.06

Abstract of disbursements made by Jno. D. McChesney, chief disbursing clerk, U. S. Geological Survey, during the third quarter of 1889.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
Jan. 10	5	J. W. Powell	Traveling expenses	$58.55
10	6	do	do	46.55
18	16	J. Karr	Irrigation instruments	30.00
21	36	Robt. Boyd	Office supplies	1.60
21	38	Adams Express Co	Freight charges	113.00
21	40	W. & L. E. Gurley	Instruments	319.05
22	41	Pennsylvania R. R	Transportation of assistants	93.30
22	45	Baltimore and Ohio R. R	do	760.50
25	72	M. W. Beveridge	Material	1.35
25	73	Adams Express Co	Freight charges	30.05
25	74	Geo. W. Davis	Traveling expenses	32.60
31	82	Pay-roll of employés	Services, January, 1889	165.00
31	85	Charles D. Poston	Services, Dec. 29, 1888, to Jan. 31, 1889	50.00
Feb. 2	101	C. E. Dutton	Traveling expenses	82.15
4	113	Chicago, Santa Fé and California Rwy	Transportation of assistants	10.25
4	118	Western Union Telegraph Co	Telegrams	6.70
11	144	Quartermaster's Dep't U. S. Army	Field material	834.72
18	165	E. S. Ritchie & Sons	Instruments	150.00
18	168	Herman Baumgarten	Supplies	3.00
28	193	William Ham Hall	Services, Jan. 7 to Feb. 16, 1889	425.00
28	195	Atchison, Topeka and Santa Fé R. R.	Transportation of assistants	159.15
Mar. 1	204	Charles D. Poston	Services, February, 1889	25.90
Feb. 28	217	Pay-roll of employés	Services, February, 1889	165.00
Mar. 6	236	Denver and Rio Grande R. R	Transportation of assistants	18.00
7	240	United Lines Telegraph Co	Telegrams	.68
7	248	Western Union Telegraph Co	do	7.34
13	257	Baltimore and Ohio R. R	Transportation of assistants	68.00
13	263	Henry J. Green	Instruments	960.40
13	265	William Ballantyne & Son	Supplies	6.40
13	267	Missouri Pacific Rwy	Transportation of assistants	55.50
13	269	Adams Express Co	Freight	47.35

Abstract of disbursements made by Jno. D. McChesney, etc.—Continued.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
Mar. 22	270	Wash. B. Williams	Miscellaneous supplies	$12.00
23	280	Burlington and Missouri River R. R.	Transportation of assistants	109.95
23	281	Geo. W. Knox	Freight charges, etc	7.08
30	303	Richard J. Hinton	Services, March 25 to 31, 1889	33.87
30	313	Pay-roll of employés	Services, March, 1889	220.32
		Total		5,109.41

Abstract of disbursements made by P. H. Christie, special disbursing agent, U. S. Geological Survey, during the third quarter of 1889.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
Jan. 7	1	Frank Harrison	Traveling expenses	$51.75
7	2	Nettlelon & Campbell	Instruments	148.00
14	3	C. E. Dutton	Traveling expenses	100.30
14	4	W. A. Farish	....do	15.90
14	5	Robert Robinson	....do	63.47
18	6	Frank P. Fisher	....do	16.45
18	7	P. H. Christie	....do	12.45
18	8	....do	Miscellaneous field expenses	35.10
18	9	W. A. McKenzie	Miscellaneous field supplies	34.30
21	10	G. W. Bond & Bro	Forage	28.70
26	11	Wm. Malboeuf	Field material	50.30
26	12	A. C. Schmidt	....do	79.00
26	13	R. C. Stewart	Field supplies	40.71
26	14	Jas. W. Queen & Co	Instruments, etc	66.13
26	15	W. & L. E. Gurley	....do	372.00
26	16	Hugh Loudon	Mules	275.00
28	17	Plaza Hotel	Subsistence	56.50
31	18	Pay-roll	Services, January, 1889	1,380.84
31	19	C. W. Taylor	Office supplies	15.00
Feb. 1	20	L. C. Rice	Field supplies	26.75
4	21	The Denver Fire Clay Co	....do	27.48
5	22	Mequillett & Macrum	....do	6.37
6	23	Hermann H. Heiser	Field material	55.00
7	24	W. E. Scott & Co	....do	46.00
7	25	R. W. Stuart & Co	....do	33.00
7	26	Hermann H. Heiser	....do	9.00
8	27	The Schiff-Carlston Grocery Co	Subsistence supplies	51.30
8	28	Mequillett & Macrum	Field supplies	8.37
9	29	Chas. H. Smith	Subsistence	53.63
12	30	Geo. T. Quinby	Field expenses	99.10
13	31	J. B. Williams	Traveling expenses	14.40
13	32	P. H. Christie	....do	22.45
13	33	P. H. Christie	Field expenses	86.84
18	34	F. H. Newell	....do	150.81
18	35	W. & L. E. Gurley	Instruments	50.00
21	36	Wall & Pursel	Field material	90.00
21	37	Hermann H. Heiser	....do	60.00
22	38	Geo. T. Quinby	Traveling expenses	20.20
25	39	Geo. T. Quinby	Field expenses	52.82
28	40	P. H. Christie	Services, February, 1889	140.00
28	41	Pay-roll	....do	125.00
28	42	....do	....do	956.66
28	43	....do	....do	125.00
28	44	H. B. Cartwright & Co	Subsistence supplies	109.55
28	45	Palace Hotel	Subsistence	18.50
28	46	R. S. Tarr	Traveling expenses	11.30
28	47	W. A. McKenzie	Field material	83.07
28	48	R. S. Tarr	Field expenses	130.16
Mar. 13	49	P. H. Christie	....do	3.00
13	50	....do	Traveling expenses	75.56
13	51	Gore, Janney & Co	Field supplies	2.25
21	52	F. H. Newell	Field expenses	177.59
31	53	Pay-roll	Services, March, 1889	1,308.11
31	54	Draper Manufacturing Co	Instruments	30.00
31	55	Harold M. Dyar	Services, March, 1889	12.90
		Total		7,114.07

Abstract of disbursements made by Mark B. Kerr, disbursing agent, U. S. Geological Survey, during the third quarter of 1889.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
Jan. 3	1	R. H. Chapman	Traveling expenses	$43.94
4	2	L. G. Stephenson	do	54.00
4	3	Robt. Muldrow	do	152.25
4	4	E. M. Douglas	do	87.40
5	6	Redick H. McKee	do	131.25
7	12	Josiah Pierce, jr	do	107.75
15	13	do	Field expenses	19.87
15	14	H. M. Wilson	Traveling expenses	107.75
15	15	G. E. Verrill	Field expenses	37.61
15	16	H. D. Bushnell	Traveling expenses	21.75
15	18	Mark B. Kerr	do	69.20
28	19	Pay-roll	Services, December, 1888	823.20
22	21	Western Union Telegraph Co	Telegrams	6.28
28	23	H. M. Wilson	Field expenses	298.00
28	24	Philip Sawyer	Traveling expenses	18.50
28	25	do	Field expenses	6.85
28	27	G. E. Verrill	Traveling expenses	98.50
28	29	Arthur P. Davis	Field expenses	82.76
28	30	do	do	19.85
28	31	do	Traveling expenses	18.50
28	32	R. Henry Phillips	Services, December, 1888	84.20
28	33	Pay-roll	do	839.95
29	38	W. A. McKenzie	Field material	53.70
29	39	Isador Ferron	Forage	20.00
29	40	D. L. Sammiss	do	23.66
29	43	Amos Scott	Services, December, 1888	60.00
29	44	Reaser Bros	Forage	18.50
29	45	Geo. Chase	Repairs, etc	20.75
29	46	Kauzenbach & Habuland	Subsistence, etc	23.58
29	47	Arthur Bishoff	Field subsistence	9.70
31	54	Pay-roll (office)	Services, January, 1889	1,311.40
31	55	do	do	258.30
31	56	Pay-roll (Davis)	do	394.16
31	57	Pay-roll (Johnson)	do	950.00
Feb. 15	63	A. H. Thompson	Traveling expenses	195.95
26	70	R. H. Chapman	Field expenses	3.00
26	71	Henry Vilas	Traveling expenses	11.70
26	72	do	do	66.70
27	73	Willard D. Johnson	Field expenses	275.15
27	76	Reaser Bros	Subsistence, etc	107.08
27	77	F. G. Pratt & Co	do	18.62
27	78	Stuart & McNair	do	33.22
27	79	McClutcheon, Payne & Co	Forage	38.03
27	80	Adolph Lea	do	9.00
27	81	Isaac N. Hoger	Pasturage, January, 1889	26.88
27	82	do	Pasturage, February, 1889	52.50
28	86	Pay-roll (Phillips)	Services, February, 1889	277.80
28	87	Pay-roll (office)	do	1,386.60
28	89	do	do	233.40
Mar. 5	91	Amos Scott	Services, January, 1889	60.00
5	92	do	Services, February, 1889	60.00
5	93	A. J. Newman	Pasturage	14.20
5	94	Willard D. Johnson	Traveling expenses	16.70
5	95	Pay-roll (Johnson	Services, February, 1889	875.40
5	96	R. Henry Phillips	Field expenses	19.80
9	102	W. & L. E. Gurley	Instruments	26.95
9	103	R. Henry Phillips	Field expenses	26.17
9	104	John W. Hayes	do	468.62
9	105	do	Traveling expenses	5.85
19	106	Willard D. Johnson	Field expenses	30.08
19	107	Isaiah Prendell	Forage	67.50
19	108	J. & J. Raycraft	do	50.00
19	110	John W. Hayes	Field expenses	24.25
23	112	Marchey Kelley	Services, January 23–30, 1889	20.00
23	113	McClutcheon, Payne & Co	Forage	32.14
23	114	do	do	7.49
23	115	Stuart & McNair	Subsistence	24.62
23	116	C. V. Mead	do	18.45
23	117	Eugene Moreno	Forage	13.50
23	118	R. Henry Phillips	Field expenses	37.53
31	122	Pay-roll (office)	Services, March, 1889	1,767.50
31	124	do	do	58.07
31	125	Pay-roll (Phillips)	do	286.10
31	126	Amos Scott	do	60.00
31	128	H. C. Daugberg	Pasturage	198.00
31	129	Jacob Klein	Storage	15.00
31	130	Thomas Clements	do	15.00
31	131	C. R. Montgomery	Pasturage	102.00
		Total		13,409.66

Abstract of disbursements made by Anton Karl, special disbursing agent, U. S. Geological Survey, during the third quarter of 1889.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
Jan. 18	1	Arthur P. Davis	Transportation and subsistence	$85.89
3	2	John Parker	do	4.00
23	3	Willard D. Johnson	do	291.06
25	4	J. W. Hays	Field supplies	297.05
25	5	do	Subsistence	113.57
Mar. 30	7	Geo. Maier	Field materlal	5.76
Feb. 2	8	Wm. Noedel	Subsistence	132.53
2	9	A. E. Laudenslager	do	59.67
2	10	VanArsdèll & Co	Field material	47.19
2	11	Geo. W. Bond & Bro	Subsistence	19.16
2	12	J. W. Miller	Field material	51.02
2	13	Mauley L. Hart	Services, December 1-24, 1888	38.71
2	14	F. Geo. Pratt & Co	Subsistence	28.18
2	15	L. B. Putney	Field material	21.49
2	16	J. J. Shumway	Services, January 21 to 31, 1889	17.74
2	17	G. W. Bond & Bro	Field material	14.53
Mar. 30	18	Willard D. Johnson	Field expenses	270.00
30	19	Samuel A. Foot	Services	4.73
30	20	W. N. Emmert	Subsistence	20.65
		Total		1,522.93

Abstract of disbursements made by John D. McChesney, chief disbursing clerk, U. S. Geological Survey, during the fourth quarter of 1889.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
April 11	9	J. Schultzbach	Supplies	$474.00
11	11	Western Union Telegraph Co	Telegrams, February, 1889	3.87
22	24	Atchison, Topeka and Santa Fé R. R.	Transportation of assistants	163.90
22	26	Denver and Rio Grande R. R	do	35.60
22	28	Chicago and Alton R. R	do	27.75
29	46	Geo. Ryneal, jr	Supplies	57.30
29	52	Crane & Co	Irrigation supplies	30.00
29	61	Adams Express Co	Freight charges	24.65
30	78	Pay-roll of employés	Services, April, 1889	320.00
May 4	95	J. S. Topham	Field Material	30.00
4	105	Western Union Telegraph Co	Telegrams	6.43
18	143	Geo. Ryneal, jr	Topographic supplies	166.00
18	144	E. W. Woodruff	Irrigation supplies	3.00
18	147	Pennsylvania R. R.	Transportation of assistants	136.85
18	149	Alvah Bushnell	Irrigation supplies	24.96
18	155	Fred. A. Schmidt	Supplies	79.00
21	161	Denver and Rio Grande R. R	Transportation of assistants	17.80
21	162	United States Express Co	Freight charges	92.70
23	181	Lyman Bridges	Services, April 2 to May 14, 1889	380.00
29	190	do	Services, May 15 to May 31, 1889	140.11
31	217	Montana Central Rwy	Transportation of assistants	5.85
31	226	Pay-roll of employés	Services, May, 1889	372.50
June 4	239	Western Union Telegraph Co	Telegrams, April, 1889	22.65
4	242	Columbia Phonograph Co	Irrigation supplies	9.96
5	246	Josiah Pierce, jr	Salary, May, 1889	100.00
5	248	Quartermaster's Department, U. S. Army.	Irrigation material	269.32
12	292	Burlington and Missouri River R. R.	Freight charges	18.15
17	316	Castle & Henshaw	Irrigation material	14.50
21	327	Pennsylvania R. R	Transportation of assistants	45.10
22	328	S. J. Haislett	Field material	36.00
27	341	Z. D. Gilman	Supplies	15.00
27	342	Wyckoff, Seamans & Benedict	Type-writer supplies	8.25
29	364	Josiah Pierce, jr	Services, June, 1889	100.00
29	374	Paul Holman	do	69.20
29	384	Pay-roll of employés	do	572.50
		Total		3,872.90

Abstract of disbursements made by P. H. Christie, disbursing agent, U. S. Geological Survey, during the fourth quarter of 1889.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
April 18	1	L. D. Hopson	Traveling expenses	$59.90
18	2	J. B. Williams	....do	36.80
19	3	William P. Trowbridge, jr	....do	47.22
19	4	....do	Field expenses	11.35
19	5	W. & L. E. Gurley	Instruments	197.20
19	6	F. H. Newell	Field expenses	106.16
20	7	W. & L. E. Gurley	Instruments	195.00
29	8	R. W. Stewart & Co.	Field supplies	88.67
29	9	Lallie & Bailey	Instruments	100.00
29	10	E. S. Ritchie & Sons	....do	250.00
30	11	Pay-roll, April, 1889	Services	125.00
May 3	12	Robert Robertson	Traveling expenses	63.40
3	13	....do	Field expenses	127.92
6	14	J. B. Williams	Traveling expenses	93.00
April 30	15	Pay-roll, April, 1889	Services	731.32
May 6	16	Harold M. Dyar	Traveling expenses	67.70
April 30	17	R. S. Tarr, April, 1889	Services	75.00
30	18	P. H. Christie	....do	148.30
May 7	19	The Schiff-Carleton Grocery Co	Subsistence supplies	35.20
8	20	G. W. Bond & Bro.	Field supplies	42.32
8	21	George E. Curtis	Field expenses	286.62
10	22	Cartwright & Griswold	Field supplies	8.50
8	23	Denver and Rio Grande R. R. Co.	Transportation	121.54
10	24	W. A. McKenzie	Field supplies	40.91
10	25	F. C. Ductscher	....do	8.50
10	26	George T. Quinby	Traveling expenses	14.22
10	27	....do	Field expenses	73.66
April 30	28	Frank Harrison, April, 1889	Services	75.00
30	29	Frederick H. Newell, April, 1889	....do	125.00
30	30	T. M. Bannon, April, 1889	....do	50.00
May 13	31	Palace Hotel	Subsistence	15.63
14	32	J. W. Mitchell	Traveling expenses	13.75
15	33	Lallie & Bailey	Instruments	300.00
20	34	R. S. Tarr	Subsistence	35.00
24	35	F. H. Newell	Traveling expenses	34.50
24	36	....do	Field expenses	164.60
24	37	F. M. Bannon	Traveling expenses	55.75
June 30	110	Lyman Bridges	....do	125.75
30	111	Frank Harrison	Field expenses	219.37
30	112	B. J. Briggs	Field material	125.00
30	113	J. B. Williams, June, 1889	Services	100.00
30	114	R. S. Tarr	Field expenses	8.62
30	115	Pay-roll, June, 1889	Services	466.66
30	116	Douglas Taylor	....do	34.50
30	117	William M. Welch	....do	34.50
30	118	H. M. Wilson	....do	197.80
30	119	P. H. Christie	Traveling expenses	19.55
30	120	William P. Trowbridge, jr	Field expenses	37.00
30	121	Pay-roll [Foote], June, 1889	Services	281.75
30	122	....do	....do	161.99
30	123	William Gilbert	....do	50.00
30	124	Harold M. Dyar	....do	50.00
30	125	Lallie & Bailey	Instruments	212.00
30	126	P. H. Christie	Field expenses	93.69
30	127	William Ham Hall, May, 1889	Services	186.81
30	128	William Ham Hall, June, 1889	....do	329.70
30	129	George T. Quinby	Traveling expenses	30.95
30	130	Curt. W. Miller, June, 1889	Services	20.00
30	131	H. M. Wilson	Field expenses	46.62
30	132	....do	....do	8.60
30	133	....do	Traveling expenses	43.60
30	134	....do	Field expenses	100.15
30	135	L. D. Hopson	....do	33.84
30	136	George T. Quinby	....do	237.05
30	137	J. B. Williams	....do	48.49
30	138	Rich. Shumway, June, 1889	Services	50.00
30	139	Goldman & Co.	Field supplies	27.97
30	140	Frank Harrison	Field expenses	4.00
30	141	R. S. Tarr	....do	5.25
30	142	A. J. Wiley	....do	39.33
30	143	George T. Quinby	....do	8.60
30	144	W. A. Farish	....do	119.71
30	145	F. H. Newell	Traveling expenses	58.65
30	146	....do	Field expenses	44.12
30	147	Robert Robertson	Services, June, 1889	75.00
30	148	R. P. Irwin	....do	50.00
30	149	W. A. McKenzie	Field supplies	7.00
30	150	L. H. Shortt	Field expenses	4.75
30	151	George E. Curtis	....do	75.97
30	152	E. S. Nettleton, May, 1889	Services	186.81

Abstract of disbursements made by P. H. Christie, etc.—Continued.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
June 30	153	J. J. Rogers	Field material	$22.75
30	154	E. S. Nettleton, June, 1889	Services	329.70
30	155	Joseph Werlin	Forage	12.00
30	156	S. H. Bodfish	Field expenses	45.98
30	157	Wall & Pursel	Field material	230.00
30	158	Edward F. Vincent, June, 1889	Services	10.00
30	159	E. S. Nettleton	Traveling expenses	21.15
30	160	W. W. Sargeant, June, 1889	Services	16.00
30	161	W. L. Wilson	do	20.00
30	162	J. A. Green	do	5.00
30	163	J. W. Nelson	do	4.50
30	164	L. H. Friend	do	5.00
30	165	A. W. Ralston	do	8.33
30	166	S. H. Bodfish	Traveling expenses	83.25
30	167	E. S. Nettleton	Field expenses	63.20
30	168	W. W. Montague & Co	Field material	72.14
30	169	R. W. Neil	do	82.25
30	170	James Smiford	Field supplies	17.45
		Total		18,004.92

Abstract of disbursements made by Mark B. Kerr, disbursing agent, U. S. Geological Survey, during the fourth quarter of 1890.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
Apr. 10	9	John W. Hayes	Field expenses	$463.44
15	10	J. W. Dobbins	Traveling expenses	3.86
15	11	S. S. Mitchell	do	4.15
15	12	Willard D. Johnson	Field expenses	93.95
18	13	Pay-roll of employés	Services, March, 1889	917.60
18	14	M. Studjuski	Field material	755.00
18	15	W. H. Hyde	do	180.00
18	16	William H. Anderson	do	250.00
18	17	F. E. M. Jayne	do	125.00
18	18	Kennedy & Co	Field subsistence	7.58
18	19	do	do	22.22
18	20	Martin Tolman	Forage	30.58
18	21	Isaac N. Hogan	Pasturage	52.50
18	23	E. M. Douglas	Traveling expenses	23.20
24	31	Willard D. Johnson	Field expenses	413.99
24	32	do	do	200.33
25	33	R. Henry Phillips	do	20.35
25	34	J. B. Hamilton	Two horses	300.00
25	35	W. H. Hyde	One wagon	90.00
30	40	Pay-roll of employés	Services, April, 1889	1,868.35
30	41	Amos Scott	do	60.00
30	43	Arthur P. Davis	Field expenses	19.15
30	44	Pay-roll of employés	Services, April, 1889	282.40
May 1	45	C. H. Fitch	Traveling expenses	19.00
11	46	Pay-roll of employés	Services, April, 1889	537.60
11	57	McCutcheon, Payne & Co	Forage	33.55
11	58	Stuart & McNair	Subsistence	14.00
13	59	R. H. Chapman	Traveling expenses	69.10
16	61	Pay-roll of employés	Services, April, 1889	455.40
22	64	E. M. Douglas	Traveling expenses	135.85
23	66	Daniel M. Adams	do	24.05
23	67	C. H. Fitch	do	33.90
23	68	Robert J. Breckenridge	do	18.25
23	69	P. V. S. Bartlett	Field expenses	39.70
23	70	R. H. Phillips	do	41.98
23	71	H. M. Wilson	do	54.75
23	72	R. C. McKinney	Traveling expenses	94.60
23	73	G. E. Verrill	do	102.25
23	74	Mark B. Kerr	do	164.08
29	75	do	Field expenses	7.25
31	78	Pay-roll of employés	Services, May, 1889	25.00
31	79	do	do	1,024.60
31	87	H. M. Wilson	do	170.40
31	89	R. H. Chapman	do	102.20
31	90	A. H. Thompson	do	255.50
31	91	Mark B. Kerr	do	153.40
June 29	94	William H. Hyde	Field material	233.85
		Total		9,993.90

SUPPLEMENTAL, JUNE 30, 1889.

Abstract of disbursements made by Jno. D. McChesney, chief disbursing clerk, U. S. Geological Survey, during the first quarter of 1890.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
July 10	13	John C. Parker	Supplies, etc	$5.90
11	20	Fauth & Co	Irrigation instruments	2,900.00
18	66	Denver and Rio Grande R. R	Transportation of assistants	34.25
18	67	Atlantic and Pacific R. R	do	28.65
20	95	Maricopa and Phœnix R. R	Freight	.52
22	100	John F. Paret	Supplies	23.55
22	121	Quartermaster's Department, U. S. Army.	Material	91.21
31	129	Northern Pacific R. R	Transportation of assistants	19.45
31	130	Baltimore and Ohio R. R	do	28.00
Aug. 1	146	Robert Boyd	Supplies	3.83
1	147	Thomas Riggs	Services	7.50
3	150	Royce & Marean	Supplies	1.80
3	157	Western Union Telegraph Co	Telegrams	4.12
3	163	do	do	3.01
6	165	Utah Central Rwy	Transportation of assistants	1.50
6	168	Idaho Central R. R	Freight	8.27
7	171	George Ryneal, jr	Material and supplies	318.99
7	177	Adams Express Co	Freight, April, 1889	10.70
7	178	do	Freight, March, 1889	7.25
10	182	Northern Pacific R. R	Transportation of assistants	41.70
15	187	Denver and Rio Grande R. R	do	139.85
15	191	Arthur Watts	Field supplies	49.00
15	192	Sparks Bros	Forage	59.60
19	195	Adams Express Co	Expressage, May, 1889	70.95
19	198	Idaho Central R. R	Transportation of assistants	1.00
19	201	Denver and Rio Grande R. R	do	51.90
19	204	do	Freight	1.20
20	207	Western Union Telegraph Co	Telegrams, May and June, 1889	51.47
21	215	Columbia Phonograph Co	Rent, April 1 to June 30, 1889	10.00
21	216	Alvah Bushnell	Irrigation supplies	24.96
21	217	Colorado Midland Rwy	Transportation of assistants	8.00
22	220	E. Morrison	Supplies	3.50
22	221	John Roach	Repairs to field material	15.50
Sept. 12	246	Colorado Midland Rwy	Transportat.on of assistants	7.05
13	248	Baltimore and Ohio Rwy	do	413.40
14	249	Adams Express Co	Freight charges, June, 1889	184.80
16	250	Fred. A. Schmidt	Irrigation supplies	12.00
19	252	Daniel M. Adams	Services, May 1 to 15, 1889	24.19
26	254	Willard D. Johnson	Field expenses	225.47
30	255	John W. Hayes	do	342.02
30	257	J. W. Powell	Traveling expenses	66.75
30	258	Atchison, Topeka and Santa Fé R. R.	Transportation of assistants	57.50
30	259	W. & L. E. Gurley	Instruments	2,158.00
		Total		7,518.31

Abstract of disbursements made by Jno. D. McChesney, chief disbursing clerk, U. S. Geological Survey, during the second quarter of 1890.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
Oct. 23	7	Henry J. Green	Instruments	$60.62
31	8	C. J. Jones	Traveling expenses	4.50
Nov. 8	23	Atchison, Topeka and Santa Fé R. R.	Transportation of assistants	126.31
11	24	Adams Express Co	Freight	6.80
12	25	Paul Holman	Traveling expenses	39.00
19	30	Baltimore and Ohio R. R	Freight	8.58
Dec. 7	34	United States Express Co	do	10.95
14	38	Willard D. Johnson	Field expenses	129.99
14	39	do	do	103.85
14	40	do	do	83.65
17	42	Chesapeake and Ohio R. R	Transportation of assistants	69.95
		Total		644.20

Abstract of disbursements made by Mark B. Kerr, disbursing agent, U. S. Geological Survey, during the first and second quarters of 1890.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
July 30	1	Wells, Fargo & Co	Expressage	$50.70
Oct. 25	2	Daniel M. Adams	Services, May, 1889	25.81
Nov. 1	4	A. T. Kyle, jr	Pasturage	10.84
		Total		87.35

Abstract of disbursements made by P. H. Christie, special disbursing agent, U. S. Geological Survey, during the first quarter of 1890.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
July 20	1	Robert Robertson	Traveling expenses	$43.95
20	2	....do	Field expenses	257.87
24	3	T. E. Farish	Services, June, 1889	100.00
26	4	A. J. Wiley	Field expenses	13.38
26	5	J. W. Mitchell	....do	19.34
31	6	S. W. Pomeroy	Hire of transportation	15.50
31	7	Harold M. Dyar	Field expenses	35.35
Aug. 10	8	Royce and Mareau	Instruments	75.00
10	9	W. & L. E. Gurley	....do	394.33
10	10	H. M. Wilson	Field expenses	53.55
10	11	Bach, Cory & Co	Field supplies	87.21
Sept. 13	12	L. H. Shortt	Field expenses	10.75
19	13	George E. Curtis	Traveling expenses	9.90
19	14	....do	....do	143.05
30	15	C. H. Treat	Instruments	18.07
		Total		1,277.25

Amount expended as per foregoing statement	$98,068.77
Amount of bonded railroad accounts for freight and passenger transportation settled through the Treasury Department	1,799.69
Balance on hand	131.54
Total	100,000.00

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